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IMPACT OF LAND USE LAND COVER DYNAMICS ON ECOSYSTEM SERVICE VALUES: A STUDY ON EASTERN HIMALAYAN REGION

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Abstract

In recent decades, researchers worldwide have been paying closer attention to biodiversity in terms of the economic valuation of ecosystem services (ESVs). Eastern Himalayan region, spanning across the Darjeeling district of West Bengal, Sikkim, NE India, and Bhutan, offers valuable ecosystem services. However, the assessment of ESVs in this region remains limited. Therefore, the present study evaluated the land use land cover (LULC) changes and their impact on the ecosystem services values (ESVs) in the Eastern Himalayan Region for the years 1992, 2002, 2012, and 2020. Using ESA CCI Land cover products (300-meter resolution), LULC maps were prepared, and ESVs were calculated based on global value coefficients adopted from the study by Costanza et al. (2014). The results reveal an increase in urban areas, wetlands, forest cover, croplands, and barren lands; with urban areas experiencing the most significant expansion (265.81%). Conversely, grasslands and water bodies decreased, indicating growing anthropogenic influences. Sensitivity analysis also confirmed the validity of assessing ESVs over time. These findings underscore the importance of integrating ESVs into decision-making processes affecting the natural world.

Keywords : Ecosystem services, Ecosystem Service Values (ESVs), Land use land cover change, Eastern Himalayan Region

Introduction

Ecosystem services encompass the numerous advantages bestowed upon society by nature. It enables human existence through the provision of healthy food, clean water, disease and climate regulation, crop pollination, soil formation, and various cultural and recreational benefits. Humans derive these services from ecosystem functions, the underlying processes within ecosystems. So, the interdependence of ecosystem functions and services is essential for supporting human welfare. Human capital (people), social capital (society), and built capital (built environment) are crucial for the flow of ecosystem services. Interactions between natural capital and its yield benefits contribute to human well-being. While ecosystem services hold significant economic value globally, they are often overlooked in decision-making due to the need for more monetary quantification in the economy. This necessitates periodic evaluation of ecosystem service (Costanza et al., 1997).

The concept of ecosystem services received greater attention from researchers after the publication of the 'Ecosystem Service Valuation Model' by Robert Costanza et al. in 1997 and the 'Millennium Ecosystem Assessment (MEA)' Report by the United Nations in 2005. The report titled 'The Economics of Ecosystems and Biodiversity (TEEB)' published by the UN Environment Program in 2010 further aroused interest in this issue among mass audiences. (Costanza et al., 2014a). Although Costanza's model was criticized for the uncertainties of the coefficients and limitations regarding their application at the local level. However, these efforts are considered fruitful and valuable for understanding various benefits arising from ecosystem functions necessary to estimate the value of ESs.

Ecosystem services evaluation connects ecology with the economy by considering additional value beyond market values. It aims to assess trade-offs associated with the ecosystem's 'relative' contribution to sustainable human well-being goals (Costanza et al., 2014a). There are several methods to quantify ecosystem services viz. market-based methods, revealed preference methods, stated preference methods, or benefit transfer methodologies. Among these, the benefit transfer is the most frequented method for its simplicity and effectiveness. Several studies have applied this method to analyze the relation of ESV of a region with LULC changes (Kindu et al., 2016; Li et al., 2019; Jiang et al., 2020; Sharma et al., 2020; Das et al., 2023). The method infers the economic values of environmental goods and services at a place by using information about the same goods at another place. It helps to estimate the economic values in monetary units of those goods and services that are not traded in markets. However, the accuracy of this method depends on the accuracy or measurement errors in the original studies (Wilson & Hoehn, 2006).

The LULC type governs the provision of ecosystem services in a given area. It creates the bridge between natural ecological processes and human socio-economic activities. It influences the supply of ecosystem services by altering the structure and composition of ecosystems (Li et al., 2019). Therefore, tracking alterations in Land Use/Land Cover (LULC) develops an understanding of shifts in ecosystem services (ESs) related to the growth of human-influenced landscapes (Sharma et al., 2020). However, the quantum of LULC change is not uniform across the regions. For instance, in their study on the Qinghai-Tibetan Plateau Jiang et al., 2020 found that total ecosystem service values (ESVs) increased between 1990 and 2015; while Gashaw et al., 2018 in their study of the Andassa watershed, Upper Blue Nile basin revealed that the ESV had declined between 1985 and 2015. Therefore, it can be said that the studies are very location-specific due to the dependency of ESV on LULC dynamics.

Among different landscapes in the world, mountains are recognized as important ecosystems by the Convention on Biological Diversity (CBD) (ICIMOD Report, 2010). The Eastern Himalayan Region has a complex and diverse physiography characterized by mountains, hills, valleys, and flood plains. They are rich in natural and crop-related biodiversity. It provides multiple essential ecosystem services like water resources, climate regulation, soil retention, carbon sequestration, and so on. However, past literature reveals that there is a dearth of studies on ecosystem services as compared to Western and

Central Himalayan regions (Rana et al., 2021). The biological diversity of the region is threatened by deforestation, degradation, forest encroachment, jhum cultivation, forest fire, illegal extraction of forest products, infrastructural development, etc. (Chatterjee et al., 2006). The region's economy is heavily reliant on forestry and agriculture and struggles with issues like unsustainable resource use and poverty (Chettri & Sharma, 2006). So, without assessing the impact of these land use changes on the ecosystems, the quantitative knowledge about ESV would be limited. Therefore, the present study aims to study the impact of land use/land cover change on Ecosystem Service Value over the region with the following objectives (1) To evaluate Land Use Land Cover changes during 1992, 2002, 2012, and 2020 over the Eastern Himalayan Region, (2) Examine the distribution of Ecosystem Service Values, and their changes over the reference years and (3) Analyse the sensitivity of ESV in response to LULC change. The findings from this study could give insights into the importance of these services and their effective management in policy and decision-making.

Study area

The Eastern Himalayan Region, the area of interest for the present study extends between 21°58' N to 29°30' N latitudes and 87°59' E to 97°30' E longitudes. It consists of Sikkim, parts of West Bengal (Darjeeling District), Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura and the entire Bhutan (Figure 1). It covers an area of about 2,80,157 sq. km. The climatic characteristics of this region are pre-humid to humid, with approximately 2,450 mm of rainfall per year. The topography of Meghalaya, Manipur, Nagaland, and Sikkim are characterized by steep to very steep slopes, whereas Assam valley has very gentle slopes. Due to variations in topography, climate, and vegetation varies considerably. The soil is red sandy to lateritic type, characterized by old and recent alluvial and terai soils.

Situated at the juncture between Asia and the Indian subcontinent, this region has a relatively young geological structure and extreme altitudinal variations and is recognized as one of the rich biodiversity regions at the global scale. The region provides multiple ecosystem services (provisioning, regulating, cultural, and supporting services); which helps to study the distribution of different ecosystem services. The ecological diversity of this region is attributed to diverse topography, soil, and climate. The region comes under the major biome of alpine, temperate, and sub-tropical forests; and lies at the intersection of multiple biogeographic regions, i.e., the Indo-Malayan Realm, Palearctic Realm, and the Sino-Japanese Region. Also, the region is classified as a part of Indo-Burma biodiversity hotspots and Himalayan hotspots.

The human population is not evenly distributed over the region. Population density is high in the Terai regions of Nepal and West Bengal; Dooars region of Assam and the population is scattered in the regions of Meghalaya, Manipur, Tripura, and Brahmaputra basin. The livelihood of a major portion of the population depends upon agriculture and allied activities. In the last three decades, the population in this region has gone up by about 2.1% annually. So, the current status regarding the impact of human influence on the biodiversity of the region needs to be understood because the Eastern Himalaya, as a unique and responsive ecosystem, demands focused consideration, especially given its vital life support functions for the conservation and sustainable development of mountain environments.

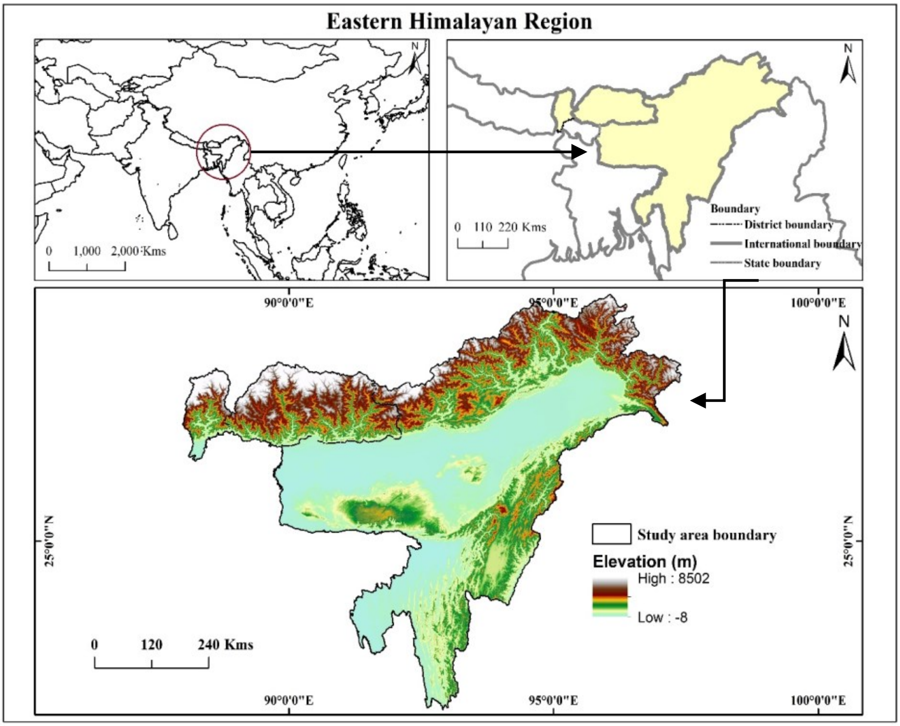

Figure 1: Location map of the study area

Materials and Methods

Database

The current research utilized annual European Space Agency Climate Change Initiative land cover (ESA CCI-LC) maps to examine changes in land use and land cover across the study area. Global land cover maps were generated from 1992 to 2020, with a resolution of 300 meters, focusing on three 5-year periods centred around the years 2010 (2008-2012), 2005 (2003-2007), and 2000 (1998-2002). Until 2015 (version 2.0.7), the land cover maps were produced within the framework of the ESA CCI initiative. Starting from 2016, the maps were operationally generated under the EC Copernicus Climate Change Service. These maps categorized land cover into 22 Level-1 classes (providing information at the global scale) and 14 Level-2 classes (offering more detailed information at the regional scale). To validate the classification results, the GlobCover 2009 dataset was employed to evaluate the accuracy of the CCI-LC map for the 2010 period, yielding a total accuracy of 73.2%. LULC maps of 1992, 2002, 2012, and 2020 are selected for the present study (http://maps.elie.ucl.ac.be/CCI/viewer) with eight major land cover classes viz. Forests, Cropland, Grassland, Wetland, Urban areas, Barren land, Waterbodies, and Permanent snow and ice are chosen to synchronize with the biomes mentioned in Constanza et al. (1997) and Constanza et al. (2014).

Methods used

Valuation of ecosystem services is a process of assessing their contribution to human welfare. Ecosystem Service Values (ESV) help to take into account the natural capital along with physical and social capital, which are equally important in sustainable human well-being. (Kubiszewski et al., 2013). Analyzing social well-being through ecosystem service valuation using monetary metrics allows for a meaningful comparison of the social benefits offered by distinct management approaches.

Numerous approaches are prevalent to aggregate both market and non-market components of ESV. The benefit Transfer method is employed to estimate the ESVs for the study area. This method estimates the Ecosystem Service Values at one location based on the existing data related to similar valuation studies and transfers those values of Ecosystem Services and other information to a similar location (Kubiszewski et al., 2013). Thus, the method works by assuming a constant unit value for each hectare of a specific ecosystem type and then calculates the total value by multiplying that constant value by the area of each type (Costanza et al., 2014a).

Estimation of Ecosystem Service Values

We have estimated Ecosystem Service Values (ESVs) for the 1992, 2002, 2012, and 2020 reference periods, and computed their changes over the years. For this purpose, those Land use/land cover types which though not exactly similar have close semblance to the biomes mentioned in Costanza et al., 2014 (Table 1) are used as proxies to estimate the ESVs of different land use/land cover types for each reference year (Kindu et al., 2016; Gashaw et al., 2018; Li et al., 2019).

Table 1: Global Value coefficients of different LULC types corresponding to equivalent biome

LULC type	Equivalent biome	Value coefficients (US$/ha/yr)
		2011
Cropland	Cropland	5567
Forest land	Forest	3800
Grassland	Grass/rangelands	4166
Wetland	Wetlands	140174
Urban area	Urban	6661
Barren land	Desert	0
Waterbodies	Lakes/rivers	12512
Permanent snow and ice	Ice/rock	0

Source: (adopted from Costanza et al., 2014)

The ESV (in US dollars) of different LULC types is calculated using Equation 1. The value coefficients (VC) adopted from Costanza et al., 2014 corresponding to different LULC types are multiplied by the area (in hectares) under each LULC type. The total ESV for a particular reference year is obtained by summing up the ESVs from each LULC type. In this way, individual and total ESVs for all the reference periods are calculated (Tables 2 and 3).

$$ESVi = \Sigma\,(Ai\ * VCi) \qquad \text{Equation (1)}$$

$ESVi$ is the Ecosystem Service Value of a particular LULC type 'i', Ai is the area (in ha) of that LULC type 'i' and VCi is Value Coefficient for that LULC type 'i' (US Dollar/ha/year)

Table 2: Area under each LULC type from 1992 to 2020

LULC types	1992		2002		2012		2020	
	Hectares	%	Hectares	%	Hectares	%	Hectares	%
Cropland	6601284	21.83	6948432	22.97	7017102	23.2	6776136	22.4
Forest land	18520245	61.23	19106919	63.17	19339065	63.94	19651482	64.97
Grassland	4329783	14.32	3381174	11.18	3049794	10.08	2948571	9.75
Wetland	8361	0.03	8982	0.03	11754	0.04	14724	0.05
Urban area	20349	0.07	26946	0.09	50886	0.17	74439	0.25
Barren land	133236	0.44	136557	0.45	161361	0.53	160389	0.53
Waterbodies	364617	1.21	368865	1.22	347913	1.15	352359	1.16
Permanent snow and ice	267930	0.89	267930	0.89	267930	0.89	268398	0.89

Source: Computed by authors

Rate of ESV change

The Changes in ESVs are obtained by taking differences in Ecosystem Service Values in each reference year. Here, we have assessed the percent change of ESVs across different periods (1992-2002, 2002-2012, 2012-2020, and 1992-2020) using the Equation 2 (Table 4).

$$C = \frac{(ESVpresent\ year - ESVinitial\ year)}{ESVinitial\ year} * 100 \qquad \text{Equation (2)}$$

Ecosystem Service Values for Individual Ecosystem Functions

Further, the ESVs provided by individual Ecosystem Functions are estimated using Equation 3. For these, 13 ecosystem services (4 provisioning services, 5 regulating services, 3 supporting services, and 1 cultural service) are considered, and the value of each Ecosystem Function is calculated by multiplying the area of each LULC type with the value coefficients of each function of each LULC type (Table 5).

$$ESVj = \Sigma\,(Ai\ * VCij) \qquad \text{Equation (3)}$$

$ESVj$ is the Ecosystem Service Value of individual ecosystem functions 'j' provided by all the LULC types, Ai is the area (in ha) of LULC type 'i' and $VCij$ is the Value Coefficient of that function 'j' for LULC type 'i' (US Dollar/ha/year)

Elasticity of the ESVs in response to LULC change

Elasticity or sensitivity analysis is performed to determine the dependency of changes in ESVs with the changes of different LULC categories using Equation 4. If a small change in LULC reflects significant ESV changes, then the elasticity will be large, which means it has high sensitivity, and vice versa. The value of elasticity is divided into three classes (Jiang et al., 2020); where an elasticity value less than 0.5 represents inelastic, between 0.5 to 1, elastic, and a value > 1, is highly elastic (Table 6).

$$E = \left\{\frac{ESVend - ESVstart}{ESVstart}\right\} / \left(\frac{\Sigma\Delta Li}{\Sigma Li}\right) \quad \text{Equation (4)}$$

E is the elasticity of ESV, $ESVend$ is the ESV at the end of the research period and $ESVstart$ ESV at the beginning of research period, ΔLi is area converted from one LULC type to the other 'i' and Li is the area of LULC type 'i'.

Results

Analysis of LULC Dynamics

The LULC dynamics of the Eastern Himalayan Region are shown in Table 2 and Figure 2. The spatio-temporal distribution of LULC shows heterogeneity over the region (Figure 3). Throughout the decades, this region has been dominated by forest cover, followed by cropland and grassland. The other land use types are sparsely distributed in some particular areas. In 1990, the forests covered 61.23% of the total area, which increased to 64.97% in 2020. More than 70% area is covered with forest lands and grasslands in the states of Sikkim, Arunachal Pradesh, Darjeeling hills in West Bengal, Meghalaya, Manipur, and Mizoram. The increase of both open and dense forest cover and the implementation of afforestation programs is attributed to the increase in forest area in the region. Cropland has increased from 21.83% in 1992 to 23.2% in 2012 and then decreased to 22.4% in 2020. The major distribution of cropland is concentrated in the state of Assam, covering the central part of the region. In the case of grassland, it has decreased from 14.32% in 1992 to 9.75% in 2020. The area of waterbodies has decreased from 1.21% in 1992 to 1.16% in 2020, but wetlands have shown a slight increase from 0.03% in 1992 to 0.05% in 2020. A positive change was noticed for urban areas, which was 0.07% in 1992 and reached 0.25% in 2020. Urban centers like Darjeeling, Siliguri in Darjeeling District of West Bengal; Gangtok, Peling in Sikkim; Thimpu, Phuntsholing, Paro in Bhutan; Tawang, Itanagar, Ziro in Arunachal Pradesh; Dimapur, Kohima in Nagaland; Imphal in Manipur; Aizawl in Mizoram; Agartala in Tripura, etc are scattered over the region and expanded in their areas over time. Barren lands are sparsely distributed throughout the area, which have gradually increased from 0.44% in 1992 to 0.53% in 2020. In contrast, permanent snow and ice cover is mainly distributed in the northernmost part of Sikkim, Bhutan, and Arunachal Pradesh, which remained unchanged for the last 28 years (0.89%). More detailed change metrics of each LULC type are given in Figure 3.

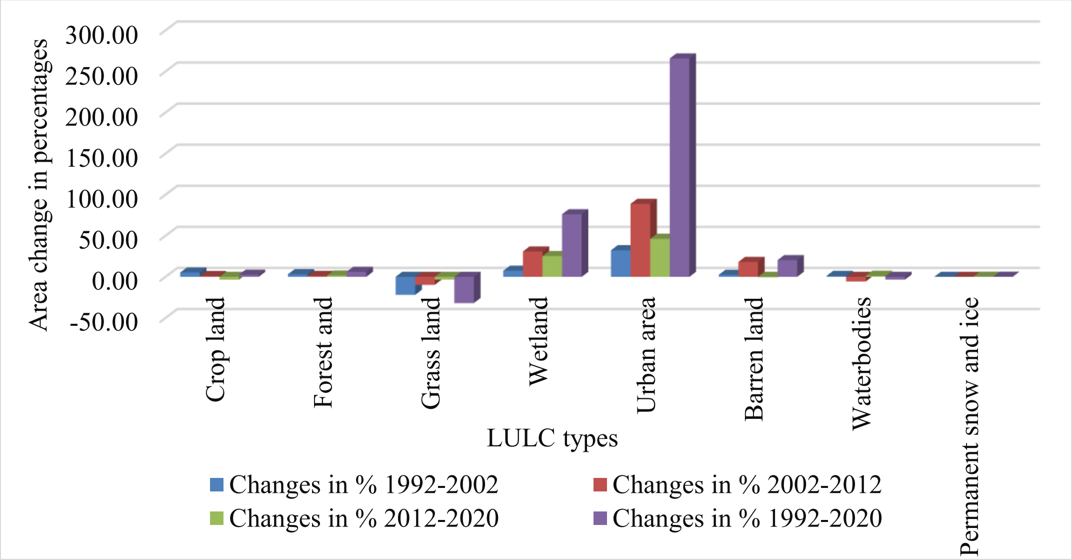

Figure 2: Spatial distribution of LULC in (a) 1992, (b) 2002, (c) 2012, and (d) 2020 over the Eastern Himalayan region

Status and changes of estimated ESVs

Table 3 shows the calculated Ecosystem Service Values (ESVs) of each LULC type during the study period. The total ESV of the region has shown a positive change from 131.034 billion US$ in 1992, 131.427 billion US$ in 2002, 131.597 billion US$ in 2012 to 131.652 billion US$ in 2020. In particular, forest land is found to be the major contributor to total ESV followed by cropland and grassland. In 1992, forest, cropland, and grassland had the ESV of 70.38, 36.75 and 18.04 billion US$ respectively. Waterbodies, wetlands, and urban areas shared very little proportion of the total ESV, i.e. 4.56, 1.17, and 0.14 billion US$, respectively. In 2002, ESVs increased for forest and cropland to 72.61 and 38.68 billion US$, respectively. However, the value (ESV) of grassland decreased to 14.09 billion US$. ESV of waterbodies, wetlands, and urban areas have increased to 4.62, 1.26, and 0.18 billion US$, respectively. In 2012, ESVs of the forest, cropland, wetland, and urban areas showed a gradual increase to 73.49, 39.06, 1.65, and 0.34 billion US$, respectively. In contrast, ESVs of grassland and waterbodies have decreased to 12.71 and 4.35 billion US$, respectively. Forest land, wetlands, urban areas, and waterbodies positively contributed to ESVs in 2020 with values of 74.68, 2.06, 0.50, and 4.41 billion US$, respectively. However, the ESVs of cropland and grassland have decreased in this period to 37.72 and 12.28 billion US$, respectively. Throughout the years, barren land and permanent snow and ice cover had an ESV of 0. Therefore, it can be said that although the

Ecosystem Service Values have differed through each LULC type within the study period, there is a total estimated gain of 618 million US$ from 1992 to 2020.

Table 3: Estimated Ecosystem Service Value of each LULC type

LULC type	Ecosystem Service Value (in billion US$)			
	1992	2002	2012	2020
Cropland	36.749	38.682	39.064	37.723
Forest land	70.377	72.606	73.488	74.676
Grassland	18.038	14.086	12.705	12.284
Wetland	1.172	1.259	1.648	2.064
Urban area	0.136	0.179	0.339	0.496
Barren land	0	0	0	0
Waterbodies	4.562	4.615	4.353	4.409
Permanent snow and ice	0	0	0	0
Total	131.034	131.427	131.597	131.652

Source: Computed by authors

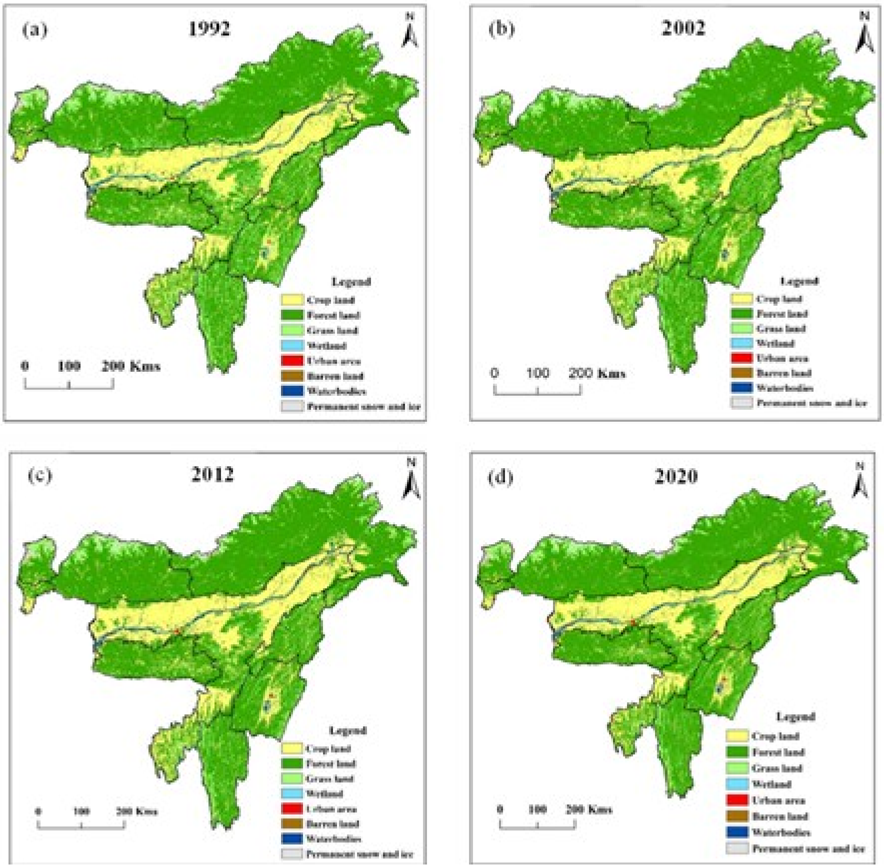

Figure 3: Area changes of LULC in Eastern Himalaya (in hectares) from 1992 to 2020

Table 4: Percentage change of total ecosystem service values under each LULC type

LULC types	ESV change (in percent)			
	1992-2002	2002-2012	2012-2020	1992-2020
Cropland	5.260	0.988	-3.433	2.650
Forest land	3.167	1.215	1.617	6.109
Grassland	-21.909	-9.804	-3.314	-31.899
Wetland	7.423	30.898	25.243	76.109
Urban area	31.618	89.385	46.313	264.706
Barren land	0.000	0.000	0.000	0.000
Waterbodies	1.162	-5.677	1.286	-3.354
Permanent snow and ice	0.000	0.000	0.000	0.000
Total	0.300	0.129	0.042	0.472

Source: Computed by authors

Changes in ESV show a gradual increase in total values in the last three decades (1992-2002, 2002-2012, and 2012-2020) from 1992 to 2020 (Table 4). In the first decade (1992-2002), total ESV increased by 393 million (0.30%), in the second decade (2002-2012) it increased by 170 million (0.13%), and in the last decade (2012-2020) it increased by 55 million (0.042%) There was a constant positive change in ESVs for forest land (6.11% in 1992-2020), wetland (76.11% in 1992-2020) and urban areas (264.71% in 1992-2020), while significant reduction of ESVs was noticed for grassland (31.90% in 1992-2020). In the case of cropland, ESV increased by 5.26% in 1992-2002 and 0.98% in 2002-2012; and then decreased by 3.43% in 2012-2020. ESV of waterbodies increased by 1.16% in 1992-2002 but decreased by 5.68% in 2002-2012 and then again increased by 1.29% in 2012-2020. Figure 4 shows the heterogeneity in the spatial distribution of resources providing ecosystem services.

Changes in estimated individual ESFs

The contribution of different ecosystem services (ESs) provided by all the LULC types toward the total ESV is presented in Table 5. During the entire study period, the prime ESs provided by major LULC types were found to be water regulation, waste treatment, water supply, etc. (waterbodies); food production, raw materials, etc. (cropland); food production, genetic resources, erosion control, gas regulation, etc. (vegetation cover). The value of Ecosystem Service Functions (ESFs) varied significantly during the study period. Among all services, the contribution of Provisioning Services to the total ESV was the highest (44%), followed by Regulating Services (24%), Supporting Services (17%), and Cultural Services (15%) in 1992. After three decades, in 2020 their contribution to total ESV has changed to 42%, 26%, 16%, and 16% respectively. In aggregate, the value of both Provisioning and Supporting services has declined by 1.65 billion US$ and 0.71 billion US$ from 1992 to 2020, while the value of Regulating and Cultural services has increased by 1.84 billion US$ and 1.35 billion US$ during the same time frame. Among them, the highest decrease is noticed for genetic resources (0.99 billion US$), followed by food production (0.93 billion US$) and habitat (0.90 billion US$) during 1992-2020. Recreational values have shown the highest increase of 1.35 billion US$ from 19.23 billion US$ in 1992 to 20.58 billion US$ in 2020.

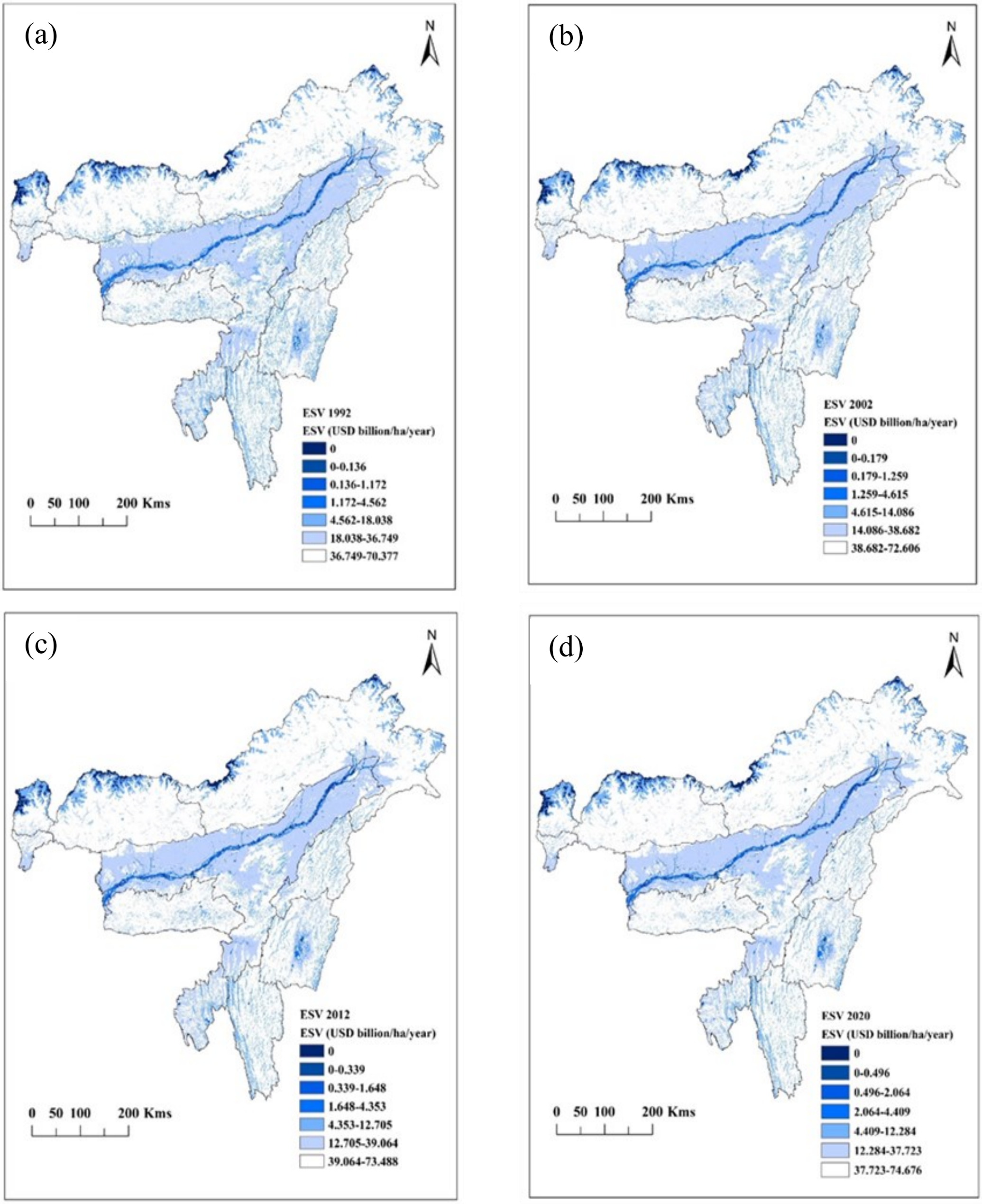

Figure 4: Spatial distribution of Ecosystem Service Values (USD billions) for (a) 1992, (b) 2002, (c) 2012 and (d) 2020

Table 5: Estimated Ecosystem Service Values of each Ecosystem Service Function in Billion US Dollars per year using Global Coefficients (adopted from Costanza et al., 2014)

Types of ecosystem services	Sub-types (f)	Ecosystem Service Functions (ESVf) provided by LULC classes in billion US$			
		1992	2002	2012	2020
Regulating Services	Climate regulation	16.074	16.602	16.804	16.945
	Water regulation	2.824	2.856	2.703	2.743
	Erosion control	2.778	2.834	2.86	2.872
	Waste treatment	6.434	6.644	6.963	7.232
	Biological control	3.485	3.566	3.598	3.641
Total R Services		31.595	32.502	32.928	33.433
Provisioning Services	Water Supply	6.216	6.39	6.396	6.349
	Food Production	25.543	25.378	25.206	24.613
	Raw materials	4.498	4.612	4.646	4.636
	Genetic resources	20.434	19.907	19.681	19.448
Total P Services		56.691	56.287	55.929	55.046
Supporting Services	Soil formation	3.780	3.971	4.01	3.886
	Nutrient cycling	1.227	1.266	1.283	1.305
	Habitat	16.824	16.044	15.82	15.927
Total S Services		21.831	21.281	21.113	21.118
Cultural Services	Recreation	19.229	19.84	20.156	20.583
Total C Services		19.229	19.840	20.156	20.583
Total		129.346	129.910	130.126	130.180

Source: Computed by authors

From 1992 to 2002, ESVs of Regulating services increased by 907 million US$, within which the value of climate regulation services showed the highest increase (528 million US$) during this period. In the case of Provisioning services, total ESV has declined by 404 million US$ due to the decreased value of food production and genetic resources (165 million US$ and 527 million US$ respectively). The value of Supporting services also declined by 550 million US$ because of the habitat quality decline by 780 million US$. The value of Cultural services has increased due to the increase in recreation values (611 million US$) during the time. For the period 2002-2012, ESV of Regulating services and Cultural services have increased by 426 and 216 million US$ respectively, whereas ESV of Provisioning services and Supporting services have decreased by 358 and 168 million US$ respectively. Within the Regulating services, the value of all the ES functions has increased except water regulation services. For the other three ecosystem services, the same pattern of changes in ESVs has been noticed in the previous decade. During 2012-2020, ESV of Regulating services, Cultural services, and Supporting services have increased by 505, 427, and 5 million US$ respectively. On the contrary, the ESV of Provisioning Services has decreased by 883 million US$. In this period, all ES function's values under Regulating services have increased, while the value of all the ES functions under Provisioning services has decreased. The value of habitat quality from Supporting services and recreational values from Cultural services has increased by 107 and 427 million US$ respectively. In summary, most of the values of ES functions have increased from 1992 to 2020 with a net increase of 0.834 billion US$ except for some ESs like water regulation (Regulating services); genetic resources and food production (Provisioning services) and habitat (Supporting services).

Sensitivity Analysis

Data from LULC changes and their relation with changes in ESVs are combined to perform the sensitivity analysis over the study area (Table 6). During 1992-2002, 2002-2012, and 2012-2020, 2.27%, 2.33%, and 6.27% were converted from one LULC type to the others, respectively, within the total geographic area. Correspondingly, the ESVs also changed by 393, 170, and 55 million US$, respectively, during the consecutive study periods. Results indicate that all the Elasticity values are less than “1”, indicating that the total estimated ecosystem values are inelastic to LULC changes. Therefore, this sensitivity analysis indicates that the ESV estimation is robust despite uncertainties on the value coefficients.

Table 6: Summary of changes in LULC and estimated total ESV with the value of Elasticity

Period	Total area (hect)	Change in area (hect)	%	in billion US$ ESV_{start}	ESV_{end}	ESV_{change}	Elasticity
1992-2002	30245805	687015	2.27	131.034	131.427	0.393	0.132041
2002-2012	30245805	704664	2.33	131.427	131.597	0.17	0.05552
2012-2020	30245805	1897218	6.27	131.597	131.652	0.055	0.006663

Source: Computed by the authors

Discussion

Impact of LULC change on ESVs

The present study evaluated the monetary value of ecosystem services (ESV) over the Eastern Himalayan Region using the LULC datasets as a proxy biome and equivalent value coefficients proposed by Costanza et al., 2014a. Here, the relation of LULC changes with changes in Ecosystem Service Values varied differently for different LULC types in the study period. In some cases, it has increased while reduced for others. For instance, the area of forest lands has increased from 61.23% in 1992 to 64.97% in 2020. Croplands have increased from 21.83% in 1992 to 22.4% in 2020. The area of wetlands has also shown a slight increase from 0.03% in 1992 to 0.05% in 2020. Urban areas increased from 0.07% to 0.25% within the period 1992-2020. Similarly, the percentage share of ESV of forest lands in the total ESV has increased from 53.71% in 1992 to 56.72% in 2020. ESV of croplands also has increased from 28.04% in 1992 to 28.65% in 2020. ESV of wetlands and urban areas have shown an increase from 0.89% to 1.57% and 0.10% to 0.38%, respectively, from 1992 to 2020. On the contrary, the decline in areas of grasslands and waterbodies has led to a decrease in the percentage of ESVs for the same LULC types. For instance, the reduction of grassland area from 14.32% (in 1992) to 9.75% (in 2020) has resulted in a decline of ESVs from 13.77% (in 1992) to 9.33% (in 2020). Likewise, the area of waterbodies has decreased from 1.21% to 1.16% and its corresponding ESV has also declined from 3.48% in 1992 to 3.35% in 2020.

Factors affecting spatial distribution of ESV

As forest land is the major contributor to the total ESV, changes in the forest ecosystem greatly affected the changes in the total ecosystem service values in the study area (Figure 5). The total increase in forest cover in the Eastern Himalayan Region played a significant role in increasing ESV during 1992-2020. Although some North-Eastern States experienced a decline due to forest encroachments for agricultural purposes. Notably, Nagaland, Arunachal Pradesh, and Assam's Hills witnessed a decrease in total forest cover, primarily driven by increased wood usage in construction. Arunachal Pradesh faced challenges like the diversion of forested land for development and shifting cultivation. Nevertheless, some species exhibited positive changes, particularly in bamboo regeneration. Arunachal Pradesh and Assam Hills witnessed the disappearance of dense forest cover, an increase in open forest, and a decrease in moderate forest from 2001 to 2015. In Mizoram, while open forest cover increased due to plantation, thin density, and dense forest canopy consistently decreased due to biomass removal; therefore, total forest cover has shown a decreasing trend. However, in Nagaland, the open forest may have disappeared, with biotic pressure emerging as a significant factor in forest decline (Sain et al., 2019).

Positive trends in forest cover are evident in Meghalaya, attributed to effective conservation policies fostering regeneration and afforestation. In Sikkim, Tripura, and Manipur, there is also an encouraging rise in dense forest cover. Meghalaya and Tripura experienced a conversion of open forest cover into dense forest, possibly facilitated by fast-growing species in the Northeast Himalayas (Sain et al., 2019). Also, the hill district (Darjeeling) of West Bengal has shown an increase in both open and dense forest cover during 2001-2021 as per the State Forest Report, India. Bhutan has also experienced an increase in forest cover during the last three decades (1990-2020) due to the implementation of annual campaigns for plantation, and social forestry by the Bhutan Ministry of Agriculture and Forest, while reduction is noticed for grassland. Deforestation was also observed in the region, but afforestation overpowered the forest cover loss during the study period (Yangchen et al., 2015; Gilani et al., 2015).

Further assessment of individual ecosystem functions of LULC classes executed that provisioning and regulating services make a comparatively larger contribution (over 60%) than supporting and cultural services across all reference years to the total ESV. Similar findings were estimated by Pradhan & Khaling (2023), who examined the economic valuation of ecosystem services over 31 sample villages of Darjeeling-Sikkim Himalaya using choice experiments from the field survey and found that local communities expressed a higher willingness to pay for regulating services (freshwater regulation). Provisioning and regulating services are more highly valued than the other two. Also, they have identified the perception of local people about the decreasing trend of provisioning services, especially freshwater availability. A gradual decrease of waterbodies has affected the ESV of water regulation, showing a reduction during 1992-2020. The increase (1992-2012) and decline (2012-2020) of croplands have impacted the decreased ESV of food production. Gradual decrease of grasslands has affected the ESV of genetic resources, and habitat as well, which has shown a negative change during the study period. On the other hand, forest land, urban areas, and wetlands have contributed to an increase in ESV of recreation by enhancing the aesthetic value of the landscape. Therefore, a thorough evaluation of ecosystem services serves as a valuable resource for comprehending and producing pertinent information for decision-making concerning the sustainable management of ecosystem services.

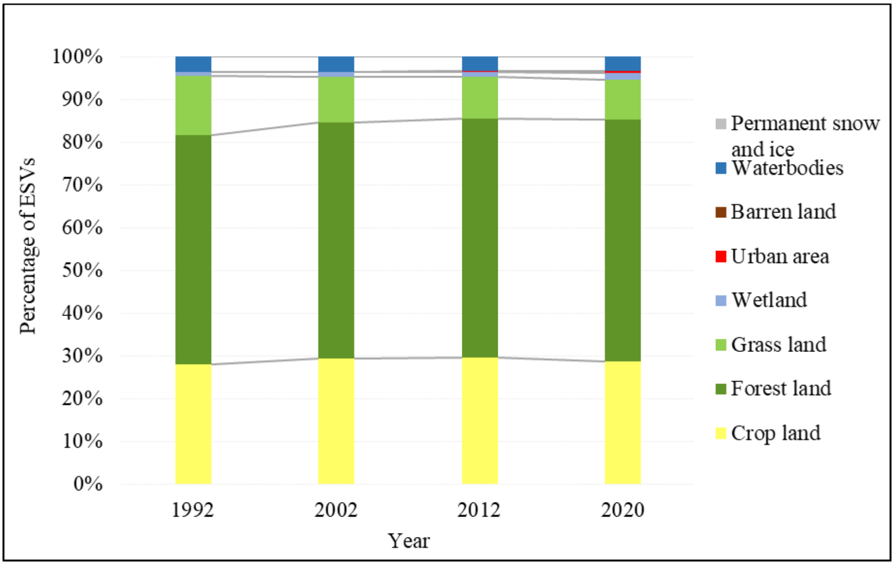

Figure 5: Contribution of different LULC types to total ESV during the study period (1992, 2002, 2012, and 2020)

Limitations and Future Perspectives

The present study has contributed to understanding ESV distribution and the impact of LULC changes on the ESVs over the Eastern Himalayan Region. Several studies have used LULC as a proxy biome to estimate the ESVs over different regions in the world (Jiang et al., 2020; Hu et al., 2020; Sharma et al., 2020; Das et al., 2023), but there is still a lack of long-term assessment of spatial heterogeneity in the Eastern Himalayan Region. There are uncertainties regarding the unit value coefficients proposed by Costanza et al., 2014a. For instance, the study doesn't consider spatial heterogeneity of ecosystem services within the ecosystems (LULC classes); which may lead to fluctuations in the result of ESVs. If we take the example of forest cover, this study has assumed the same value coefficient for all types of forest cover, therefore, providing the same ESV for all of them. In reality, tropical and temperate forests provide different ecosystem services in terms of provisioning or regulating services; which will reflect some kind of variation in the ESVs for both cases. The analysis employed global land cover data to evaluate Ecosystem Service Values (ESVs) at a relatively low resolution (300*300 m per pixel). This coarse resolution may lead to inaccuracies in quantifying the spatial extent of Land Use and Land Cover (LULC) categories. Also, the study has not taken into account the inflation in current market prices, which may impact the ESVs over time. Therefore, the inclusion of these factors in future studies will enhance the efficiency and applicability of the research.

Conclusion

A combination of LULC proxy and unit value transfer is the simplest and most effective approach for evaluating ESV in vast regions, especially where fieldwork is challenging and expensive due to harsh natural conditions, resulting in limited primary data. We have applied this approach to the Eastern Himalayan Region which emerges as a crucial provider of multiple essential ecosystem services. The study sheds light on ESV changes in response to LULC dynamics in the Eastern Himalayan Region, revealing an improvement in total and individual ecosystem services. The total ESV has increased by 618 million US$ from 131.034 billion US$ in 1992 to 131.652 billion US$ in 2020. Forests, followed by cropland and grassland, emerge as primary contributors to the total ESV in the region. Therefore, the increase in ESVs was mainly linked to the increase in forest cover as a result of afforestation, which is identified to be the main provider of ecosystem services. Among individual ecosystem service functions (ESV) provisioning and regulating services make a comparatively larger contribution (over 60%) than supporting and cultural services across all reference years to the total ESV. The contribution of individual ecosystem functions increased throughout the study period. Significant declines have occurred in the values of specific ecosystem service functions such as water regulation (Regulating services); genetic resources and food production (Provisioning services) and habitat (Supporting services). Sensitivity analysis reveals all elasticity values to be considerably below “1”, affirming the validity of assessing ESVs over the study periods to understand their responsiveness to LULC dynamics. These initial assessments underscore the importance of ecosystem services in the region, setting the stage for more thorough and precise estimations in subsequent analyses.

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