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Measuring the Ecosystem Services Value of Kalimpong District (West Bengal), India with Respect to Land Use Land Cover Dynamicity

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Abstract

Ecosystem services may be defined as profits human gain from ecosystems and it provided four major categories of ecosystem services like cultural, regulating, provisioning, and supporting service also known as ecological integrity. Ecosystem is the main base for creation of service which is essential for people benefits. In this paper, LULC map of the district are prepared by satellite image landsat-5 for 1991 and landsat-8 for 2021 using ArcGIS 10.3.1 software. The district is characterised by seven categories of LULC like water bodies, build up area, agriculture land, agriculture plantation, agriculture fallow land, social forestry and forest. Forest cover area and agriculture plantation of district were reduced from 1991 to 2021 because forest cover area was 51.47 % in 1991 and 36.94 % in 2021 and area of agriculture plantation was 9.81% in 1991 and 7.49 % in 2021. The LULC map was applied along with coefficient of ecosystem service values of biomes that propounded by Costanza and his group 1997 and 2014 to understand the spatio-temporal transformation in the value of ecosystem service of landscape. The paper represents a total of US$ 3.83 million of ecosystem services was decreased as per Costanza and his group, 1997 and US$ 1.37 million of ecosystem services was increased as per Costanza and his group, 2014 due to LULC transformation from 1991 to 2021. Ecosystem service value of forest cover area was reduced. Coefficient of sensitivity analysis applied to evaluate the reliability of ecosystem service value and finally the output results are more reliable due to the value of coefficient of sensitivity is <1 that indicates inelastic.

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Introduction

Ecosystem is the locally obvious place of the surface of the earth on which materials and energy exchange among organisms and it physical environment selected place.[6] The ecosystems give a direct and indirect material, such as food production, fresh water and services like carbon sequestration, climate regulation, aesthetic benefits and water purification.[20] Ecosystem services are defined as the advantages which human gain from the procedure of ecology that profit for people wellbeing.[19, 10] Each and every ecosystem gives a unique and different category of services such as woodland ecosystem provides dissimilar services in compare to grassland or desert ecosystem.[8] Ecosystem services trust on the transformation spatial processes which are interacting and acting continuously but considering relationship and spatial processes are limited.[1] LULC dynamics are the prime factors for change of the surface of the earth.[28] In the recent time, LULC are transformed by population growth, urban expansion and economic development in all over the world. The dynamics of LULC has a main influence on the ecosystems of the world. Natural landscapes such as forest cover areas are converted into other LULC categories such as build up area and cropland etc.[7, 16] Natural ecosystem converted into plantations, cropland and build up areas that increase fiber, timber, food production and housing, therefore, caused a decrease in other ecosystem services.[11, 21] About, 60% ecosystem service of the earth was expected to be decreased in past five decades,[20] by increase of the human population.[4]

The changes of ecosystem services have been taken areas due to human activities like LULC dynamics,[2,25] over-exploitation,[13] wildfires,[29] urbanization,[18] and natural hazards.[26] The LULC transformation patterns are more unique and complicated in India in compare to another countries.[11] The productive agriculture land, water bodies, forest converted into settlement areas that cannot able to give ecosystem services in India.[22] A group of scientists worked on the topic and reported same thing.[9, 14,15,23,24] Recently, the impact of LULC dynamics on ecosystem services which have befit the more demotic and pertinent topic for researches.[3, 5, 25, 12, 27, 30, 31] The study area gives maximum no of ecosystem services of various LULC pattern and no work has been done in the study place yet on the topic. So, keeping its in mind, the main aims of this paper are (i) Assess the spatio-temporal transformation of LULC during the period of 1991 to 2021, (ii) Assess the changes of ecosystem service value (ESV) with LULC dynamics and (iii) Finally evaluate the elasticity of ecosystem services value (ESV) with respect to LULC change.

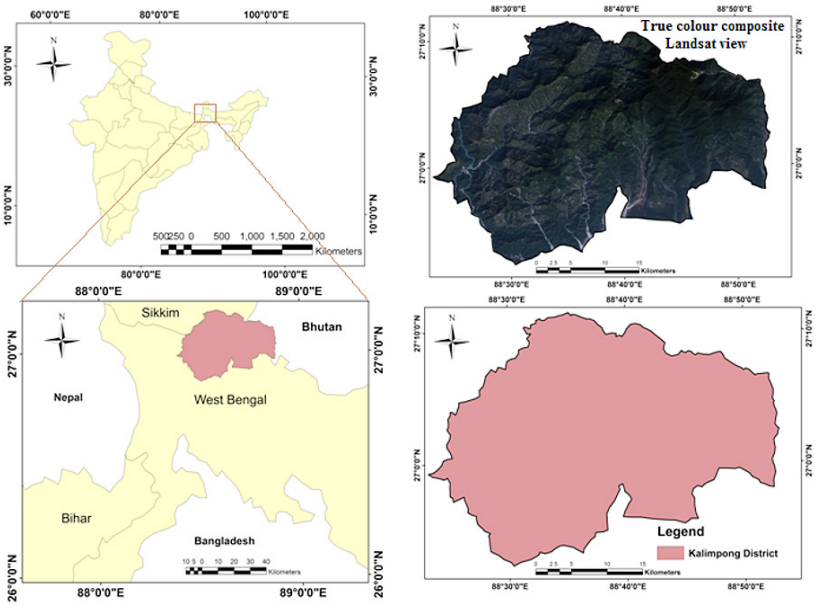

Fig. 1: Location of study area

Location and Description of Study Area

Kalimpong district is situated in eastern Himalaya. It's extending from 88º22'49''E to 88º52'35''E and 26º52'27''N to 27º11'37''N (Fig. 1). Elevation of the district ranges from 64 to 3187 metres and slope ranges from 0º to 78.10º. The district is characterized by five categories of soil such as Coarse loamy, Fine loamy - Coarse loamy, Gravelly loamy, Gravelly loamy - Coarse loamy and Gravelly loamy - Loamy skeletol. The district consists with four geomorphological units such as Fluvial origin and piedmont alluvial plain, Fluvial origin and active flood plain, Structural origin and highly dissected hills and valleys, Structural origin and moderately dissected hills and valleys as per Bhuban mapper. Major River of this district is Teesta, Dharla, Jaldhaka, Rangpo and Relli river. Total area of this district is 1053.60 km2 (105360 hectares) which incorporates 3 blocks such as Kalimpong-1, Kalimpong-2 and Gorubathan. Total population of the district was 225,220 in 2001 and 251,642 in 2011 (Census of India).

Materials and methods

Descriptions and Processing of Satellite Images

Landsat-5 TM satellite image for 1991 and Landsat-8 OLI for 2021 are used for long term LULC classification and mapping of Kalimpong district. Table 1 shows the details description of satellite images. The techniques involve (a) re-projecting all satellite data, (b) atmospheric and radiometric correction of satellite image (based on atmospheric and solar angle correction), (c) Clipping the satellite images based on purposive study area, (d) supervised classification of clipping satellite images by image classification tools of ArcGIS 10.3 and (e) lastly apply union tool for analysis of the LULC changes.

Table 1: The details of satellite images

Satellite data	Sensors	Path/Row	date	Spatial resolution
Landsat-5	TM	139/041	24/11/1991	30 m
Landsat-8	OLI/TIRS	139/041	10/11/2021	30 m

Method for Lulc Classification and Validation

In this paper, a supervised classification technique is used in ArcGIS 10.3 software. In this, an image classified applying polygons (training samples/ signature) which marked individual sample areas of various LULC groups to be classified based on supervised classification (maximum likelihood) in ArcGIS 10.3.1. LULC map are constructed based on satellite image landsat-5 for 1991 and landsat-8 for 2021 using ArcGIS 10.3.1 software. Kappa coefficient is utilised for the validation of LULC map of the district. The equation 1 is used for the measure of Kappa statistic K.

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_i + Xx_{+1})}{N^2 - \sum_{i=1}^{r}(x_{ii} Xx_{+1})} \quad ...(1)$$

Where; r means no of columns and no of rows in matrix, N means sum no of observations, Xii means observation of column i and observation of row i, X+i means sum of column i in marginal and Xi+ means sum of row i in marginally

Calculation of Ecosystem Service Value

In this paper, benefit transfer method is applied for measure the values of ecosystem service in different LULC and their transformation.[8] Ecosystem service values in different LULC has been calculated based on tantamount value of coefficient (Table 6) and area using the following equations 2 and 3 which is evolved from the framework that propounded by Costanza and his group (1997).

$$\text{ESVt} = \sum \text{AK} \times VK \quad ...(2)$$

$$\text{VK} = \sum_{i=1}^{n} ESVKI \quad ...(3)$$

Where, ESVt indicates sum ESV, VK indicates coefficient of K, AK indicates the area of K, and ESVKI indicates I category of ESV for K.

Changes of Ecosystem Service Value (Esv)

The dynamics of ESV are measured by the equation 4 that derived from Kindu *et al* (2016).

Changes of ESV =(ESV recent year-ESV previous year)/(ESV previous year) ×100 ...(4)

Where, ESV recent year indicates the end period of the study area and ESV previous year indicates beginning period of the study area.

Contribution of changes in ESV (CCk) has been measured by the equation 5.

CCk=(ESV recent year-ESV previous year)/(Total ESV previous year) ×100 ...(5)

Where, ESV recent year indicates the end period of the study area, ESV previous year indicates beginning period of the study area and total ESV previous year indicates Total ESV in beginning period of the study area.

Analysis of Sensitivity Index (SI)

In this study, sensitivity index is calculated for evaluate the credibility of ecosystem service value result due to the biomes that are used as assumes for the LULC of the study area which are not matched with the biomes that propounded by Costanza and his group (1997, 2014). A simple method has been used to estimate the coefficient of sensitivity as shown in equation 6.

CS=(VCik Ak)/ESVi ...(6)

Where, ESVi indicates the total ESV in i year, VCik indicates sum value of ecosystem services given by k at i year and Ak indicates the area of k at i year. In case, the value of sensitivity index is >1 that indicates elastic and <1 that indicates inelastic and resultant ESV is more reliable.

Results and Discussion

Changes in Land use Land Cover Classes and Validation

LULC map are prepared by supervised classification techniques within ArcGIS 10.3.1 software environment. LULC of the district is categorised into seven types such as water body, build up area, agriculture land, agriculture plantation, agriculture fallow land, social forestry and forest during the period of 1991 to 2021 (fig. 2). Spatial ordination and categories of seven LULC of the district are extracted from Landsat images such as Landsat-5 for 1991 and Landsat-8 OLI for 2021 and it details are given in table 1 and 2.

Table 2: presents the various LULC types with percentage

Year/ LULC	1991 Area		2021 Area	
	(Ha)	(%)	(Ha)	(%)
Water body	3450.69	3.27	4561.36	4.32
Build up area	4380.98	4.15	5375.55	5.10
Agriculture land	8953.93	8.49	17707.54	16.80
Agriculture plantation	10344.20	9.81	7893.48	7.49
Agriculture fallow land	11376.20	10.79	17247.91	16.37
Social forestry	12620.10	11.97	13647.64	12.95
Forest	54233.90	51.47	38926.52	36.94
Total	105360	100	105360	100

The result acquired from classified image of Landsat-5 TM (Fig. 2.A) shows that the major part of the district in 1991 was covered by forest accounted for 54233.90 ha (51.47 %) while social forestry accounted for 12620.10 ha (11.97 %) followed by agriculture fallow land 11376.20 ha (10.79 %), agriculture plantation 10344.20 (9.81 %), agriculture land 8953.93 (8.49 %), build up area 4380.98 (4.15 %) and water body 3450.69 (3.27 %) respectively (Table 2).

Finally, the result of LULC analysis for 2021 from Landsat-8 OLI (Fig. 2.B) shows that large part of the land in the district was covered by forest which accounted for 38926.52 ha (36.94 %) followed by agriculture land 17707.54 ha (16.80 %), agriculture

fallow land 17247.91 ha (16.37 %), social forestry 13647.64 ha (12.95 %), 7893.48 ha (7.49 %), build up area 5375.55 ha (5.10 %) and 4561.36 ha (4.32 %) respectively. From the result of long term analysis of LULC in the study area, it is clear that forest and agriculture plantation have continuously decreased and build up area, agriculture land, agriculture fallow land and social forestry have gradually increased in the period of 1991 to 2021(Table 2).

Table 3: Accuracy assessments in 1991

LU/LC classes	WB	B	AL	AP	AFL	SF	F	Sum (User)	Commission error (%)	User's accuracy (%)
WB	44	1	0	1	2	1	1	50	10	90
B	0	46	1	1	0	2	0	50	8	92
AL	0	0	48	0	1	1	0	50	2	98
AP	1	0	1	46	0	1	1	50	8	92
AFL	0	0	1	0	47	1	1	50	6	94
SF	0	0	1	0	1	48	1	50	4	96
F	0	1	0	1	0	1	47	50	8	92
Total (Producer)	45	48	51	49	51	55	51	350		
Omission error (%)	2.22	4.16	5.88	6.12	7.84	12.72	7.84	Overall accuracy (%) = 93.14		
Producer accuracy (%)	97.77	95.83	94..11	93.87	92.15	87.27	92.15	Kappa coefficient (%) = 92.00		

Note: WB = Water body, B = Build up area, AL = Agriculture land (Single crop), AP = Agriculture plantation, AFL = Agriculture fallow land, SF = Social forestry and F = Forest

Table 4: Accuracy assessments in 2021

LU/LC classes	WB	B	AL	AP	AFL	SF	F	Sum (User)	Commission error (%)	User's accuracy (%)
WB	48	0	0	0	0	1	1	50	10	96
B	0	47	1	0	1	1	0	50	8	94
AL	0	1	48	1	0	0	0	50	2	96
AP	0	0	1	47	1	1	1	50	8	94
AFL	0	0	0	1	47	1	1	50	6	94
SF	0	0	0	0	1	48	1	50	4	96
F	1	0	0	1	1	1	47	50	8	94
Total (Producer)	48	48	49	50	51	53	51	350		
Omission error (%)	00	2.08	2.04	2.04	7.84	9.43	7.84	Overall accuracy (%) = 94.85		
Producer accuracy (%)	100	97.91	97.95	97.91	92.15	90.56	92.15	Kappa coefficient (%) = 94		

Note: WB = Water body, B = Build up area, AL = Agriculture land (Single crop), AP = Agriculture plantation, AFL = Agriculture fallow land, SF = Social forestry and F = Forest

The results of Kappa Coefficient and overall accuracy for selected years of 1991 and 2021 are shown in table 3 and 4. The output results in the classified images of the district are above 80 percent which indicated to highly acceptable and these are useful for present study. Fig. 3 represents LULC transformation from 1991 to 2021.

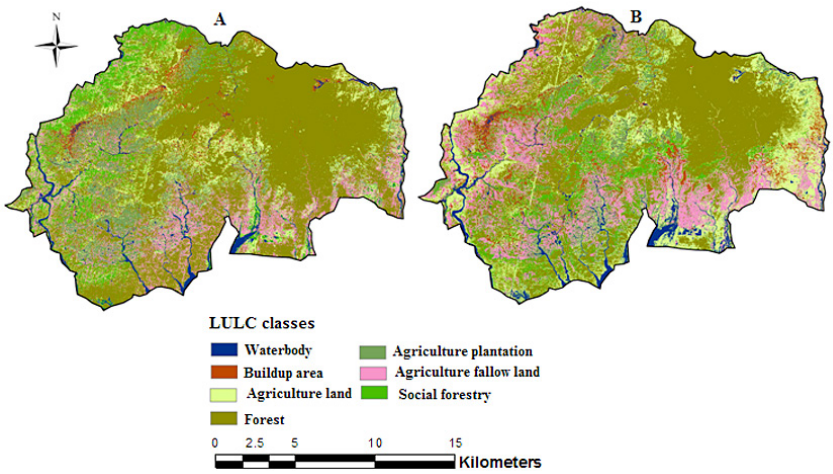

Fig. 2: LULC classes A. 1991 and B. 2021

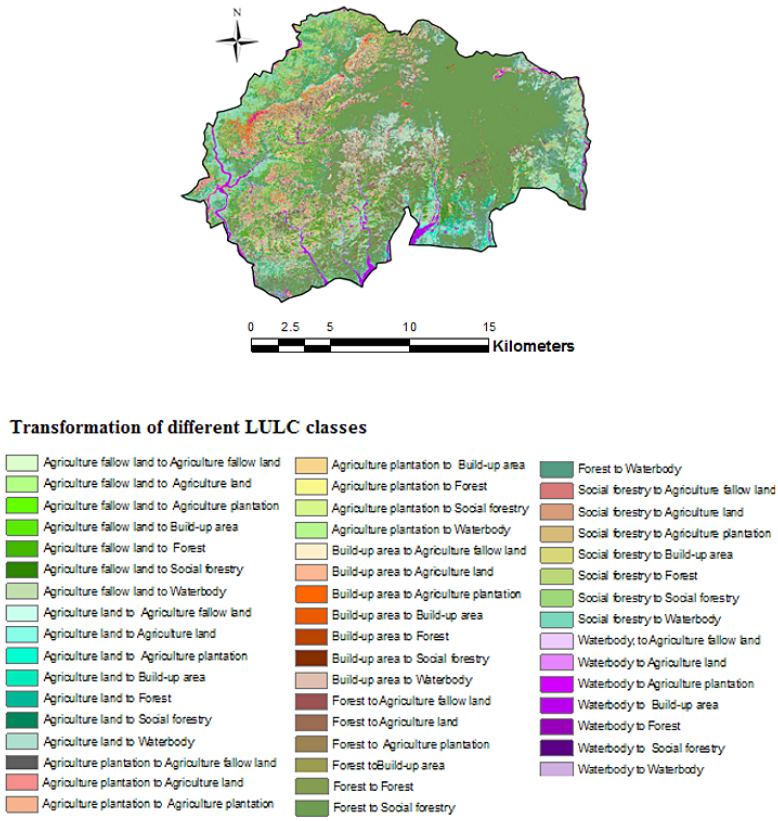

Fig. 3: LULC transformation map

Table 5: Overview of area changing rate in the period of 1991 to 2021

Year / LULC	1991 - 2021	
	Area changing rate (%)	
	(IR)	(DR)
Water body	0.70	
Build up area	2.17	
Agriculture land	8.95	
Agriculture plantation		-2.23
Agriculture fallow land	7.13	
Social forestry	8.65	
Forest		-27.08

Gain and Loss of LULC Classes

The result of overall analysis, it is clear that the area of forest and agriculture plantation remarkably decreased with the rate of 27.08 % and 2.32 % respectively in the period of 1991 to 2021 (Table 5 and fig. 4).

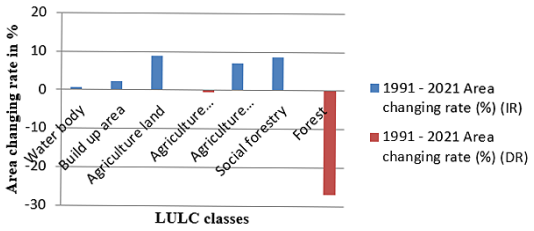

Fig.4: Total loss and gain LULC classes in 1991 to 2021

Measure of Ecosystem Service Value (Esv)

The total ecosystem services value of variant LULC is measured by Costanza and his group 1997 and 2014 for the years in 1991 and 2021 (Fig. 5). In 1991, total ecosystem services value was 95.86 US$ million/yr and 433.82 US$ million/yr as per Costanza and his group 1997 and 2014 in which the amount of contribution of forest was maximum 52.55 US$ million/yr and 206.08 US$ million/yr as per global coefficient value 1997 and 2014. The contribution of water body and social forestry were 29.32 US$ million/yr and 12.22 US$ million/yr as per Costanza and his group 1997 while 43.17 US$ million/yr and 47.95 US$ million/yr were measured as per Costanza and his group 2014 (Table 7).

In 2021, total value of ecosystem services was 92.03 US$ million/yr and 435.19 US$ million/yr as per Costanza and his group 1997 and Costanza and his group 2014 in which the amount of contribution of water body was maximum 38.76 US$ million/yr and the contribution of forest was highest 147.92 US$ million/yr as per global coefficient value 1997 and 2014. The amount of contribution of forest and social forestry were 37.71 US$ million/yr and 13.22 US$ million/yr as per Costanza and his group 1997 while the contribution of agriculture land and social forestry were 98.59 US$ million/yr and 51.86 US$ million/yr were estimated by Costanza and his group 2014 (Table 8). The amount of contribution of ecosystem services of water body is maximum increased in the period of 1991 to 2021 as per Costanza and his group 1997 while the amount of contribution of ecosystem services of agriculture land is maximum increased in the period of 1991 to 2021 as per Costanza and his group 2014 (Table 7 and 8).

Table 6: LULC and ESV based on Costanza and his group 1997 and 2014

LULC categories	tantamount biome	coefficient value (USD/ha/yr)	
		1997	2014
Water body	Wetlands and rivers	8498	12,512
Build up area	Urban	-	6661
Agriculture land	Cropland	92	5567
Agriculture plantation	Cropland	92	5567
Agriculture fallow land	Barren land	-	-
Social forestry	Forest	969	3800
Forest	Forest	969	3800

Table 7: Total ecosystem services values in 1991 as per Costanza and his group 1997 and 2014

LULC types	Total ecosystem services value in US$ million/yr	
	Costanza and his group	
	1997	2014
Water body	29.32	43.17
Build up area	-	29.18
Agriculture land	0.82	49.85
Agriculture plantation	0.95	57.59
Agriculture fallow land	-	-
Social forestry	12.22	47.95
Forest	52.55	206.08
Total	95.86	433.82

Table 8: Total ecosystem services values in 2021 as per Costanza and his group 1997 and 2014

LULC types	Total ecosystem services value in US$ million/yr	
	Costanza and his group	
	1997	2014
Water body	38.76	57.07
Build up area	-	35.80
Agriculture land	1.62	98.59
Agriculture plantation	0.72	43.95
Agriculture fallow land	-	-
Social forestry	13.22	51.86
Forest	37.71	147.92
Total	92.03	435.19

Table 9: Dynamics of ESV and contribution of dynamics of ESV in 1991 to

LULC types	1991		2021	
	Changes in US$ million/yr	CCK in %	Changes in US$ million/yr	CCK in %
Water body	9.44	9.84	13.90	3.20
Build up area	-	-	6.62	1.52
Agriculture land	0.80	0.83	48.74	11.23
Agriculture plantation	-0.23	-0.23	-13.64	-3.14
Agriculture fallow land	-	-	-	-
Social forestry	1	1.03	3.91	0.89
Forest	-14.84	-15.47	-58.16	-13.40

Changes of Ecosystem Service Value (Esv)

In this study, changes of net ecosystem service values have been estimated depend on two coefficient value of 1997 and 2014. Positive change rate was found in water body, agriculture land and social forestry as per Costanza and his group 1997 and water body, build up area, agriculture land and social forestry as per Costanza and his group 2014. Same condition was found in contribution of changes depend on Costanza and his group 1997 and 2014 (Table 9).

Table 10: ESVs after adjustment coefficient of valuation (CV) and coefficient of sensitivity (CS) in Kalimpong district

	1991				2021			
	Costanza and his group, 1997		Costanza and his group, 2014		Costanza and his group, 1997		Costanza and his group, 2014	
LULC types	**%**	**CS**	**%**	**CS**	**%**	**CS**	**%**	**CS**
Water body± 50 %	15.29	0.30	4.97	0.09	21.05	0.42	6.55	0.13
Build up area± 50 %	-	-	3.36	0.06	-	-	4.11	0.08
Agriculture land± 50 %	0.42	0.00	5.74	0.11	0.88	0.01	11.32	0.22
Agriculture plantation± 50 %	0.49	0.00	6.63	0.13	0.39	0.00	5.04	0.10
Agriculture fallow land± 50 %	-		-		-	-	-	-
Social forestry± 50 %	6.37	0.12	5.56	0.11	7.18	0.14	5.95	0.11
Forest± 50 %	27.40	0.54	27.75	0.47	20.48	0.40	16.99	0.33

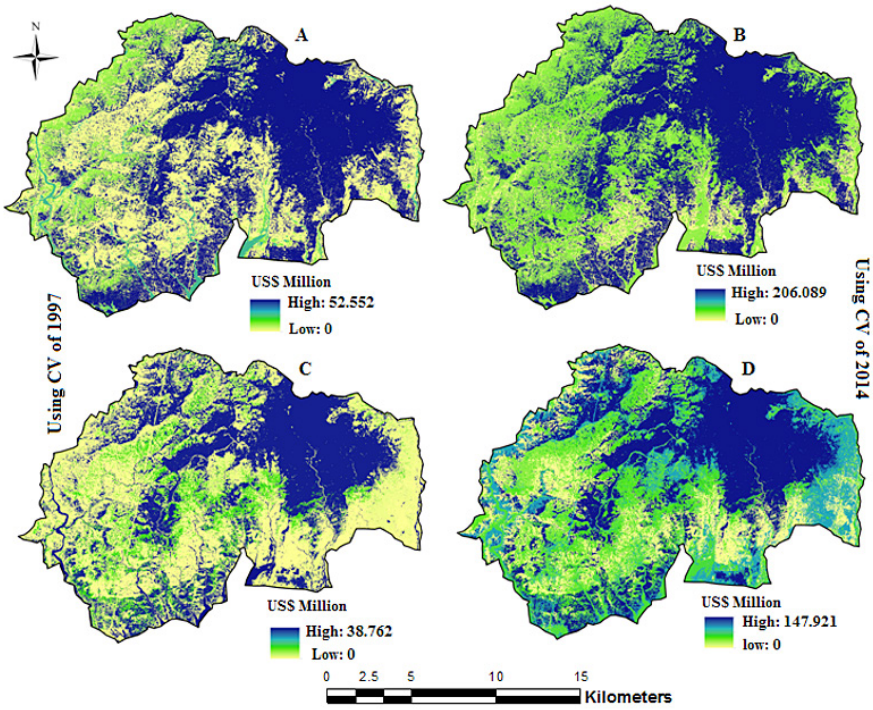

Fig. 5: Total ecosystem service value; A,B represents in 1991 as per Costanza and his group 1997 and 2014 and C,D represents in 2021 as per Costanza and his group 1997 and 2014

Analysis of Sensitivity Index (Cs)

Table no 1.10 represents coefficient of sensitivity of variant LULC. The coefficient of sensitivity of different LULC are less than 1 which indicated to the calculated ecosystem service values are low sensitive (inelastic) with respect to coefficient of valuation (CV). The lowest and highest coefficient of sensitivity value is recorded for 0.00 in agriculture land and 0.54 in forest cover area in 1991 as per Costanza and his group 1997 and 0.06 in build up area and 0.47 in forest cover area when CV for all different LULC types are adjusted by 50% (Table 10).

Conclusion

In this work, the dynamic of ecosystem service values are analyzed by the LULC dynamicity. The satellite images are applied to categories the LULC map of the district and estimated ecosystem services value using the coefficient value of Costanza and his group 1997 and 2014. The study shows agriculture plantation and forest cover area are continuously decreased in the study period. Ecosystem services of agriculture plantation and forest cover area are decreased as per Costanza and his group 1997 and 2014. This paper can be contribute to the help of the policy makers and planners to take decision for proper planning implementation for further improvement and development of environment and ecology of the district in future. It can further contribute in advancement the land use pattern in the district. At the same time, it is found that only minimum number of studies has been done in West Bengal, India at local and regional level. So, these kinds of works are need in India at the local and regional levels.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study are available on request from the corresponding author.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Authors' Contribution

Paban Ghosh: Conceptualization, Methodology, Software, Formal analysis, Visualization, Data curation, Writing – original draft, preparation, Investigation, Writing – review & editing.

Dr. Kabita Lepcha: Conceptualization, Methodology, Writing – original draft, preparation, Investigation, Writing – review & editing, Supervision.

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