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# Ecosystem services in different agro-climatic zones in eastern India: impact of land use and land cover change

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**Abstract** Land use and land cover (LULC) change have considerable influence on ecosystem services. Assessing change in ecosystem services due to LULC change at different spatial and temporal scales will help to identify suitable management practices for sustaining ecosystem productivity and maintaining the ecological balance. The objective of this study was to investigate variations in ecosystem services in response to LULC change over 27 years in four agro-climatic zones (ACZ) of eastern India using satellite imagery for the year 1989, 1996, 2005, 2011 (Landsat TM) and 2016 (Landsat 8 OLI). The satellite images were classified into six LULC classes, agriculture land, forest, waterbody, wasteland, built-up, and mining area. During the study period (1989 to 2016), forest cover reduced by 5.2%, 13.7%, and 3.6% in Sambalpur, Keonjhar, and Kandhamal districts of Odisha, respectively. In Balasore, agricultural land reduced by 17.2% due to its

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conversion to built-up land. The value of ecosystem services per unit area followed the order of waterbodies > agricultural land > forests. A different set of indicators, e.g., by explicitly including diversity, could change the rank between these land uses, so the temporal trends within a land use are more important than the absolute values. Total ecosystem services increased by US\$ $1296.4 \times 10^5$ (50.74%), US\$ $1100.7 \times 10^5$ (98.52%), US\$ $1867 \times 10^5$ (61.64%), and US\$ $1242.6 \times 10^5$ (46.13%) for Sambalpur, Balasore, Kandhamal, and Keonjhar, respectively.

**Keywords** Agro-climatic zone · Ecosystem function · Ecosystem service value · Land-use and land-cover change

## Introduction

An ecosystem service is the integration of functional entities including habitat, natural biological system properties and various processes of the ecosystem. This also includes the goods and services provided by ecosystems that represent the benefits to human populations, directly or indirectly. Different ecosystems provide an extensive range of services which differ in quantity as well as quality (MEA 2005). Ecosystem services help in sustaining human well-being and life on earth. In recent years, due to anthropogenic activities and climate change, significant changes in land use and land cover (LULC) have taken place. These changes could be due to change in cropped area and other agricultural activities, human settlements, industrial built-up areas, and mining activities (Kindu et al. 2016; Haines-Young et al. 2012; de Groot et al. 2010). Studies have indicated that impacts of LULC on ecosystem services vary across space and time (Bryan 2013; Costanza et al. 2014; Haines- Young et al. 2012; de Groot et al. 2012).

Satellite remote sensing has opened up new possibilities for obtaining precise and convenient geospatial data portraying changes in land cover and land utilization of different landscapes on earth. Satellite imagery using modern remote sensing (RS) techniques provides effective methods for acquiring data on patterns and spatial distribution of land use and land cover (Elvidge et al. 2004). It is important to assess the variation in direct and indirect ecosystem service arising from land use change (Si et al. 2014). Ecosystem valuation coefficients have been prepared for estimating monetary values of various ecosystem services generated by different biomes (Costanza et al. 1997).

While using remote sensing techniques to evaluate land use changes, and ecological services, Liu et al. (2012) reported that ecosystem services in response to human-induced land use changes decrease due to a decline in farmland and grassland. LANDSAT TM and/or ETM data have been used for estimating changes in land use and associated decline in ecosystem service value in Dongtan island (Zhao et al. 2004) and Daqing (Zhou et al. 2017) in China. Soil formation and retention was the most impacted service by land use changes among all services in watersheds of the Loess plateau, China (Si et al. 2014).

The ecosystem service is a collective assessment and valuation of different positive and negative components of ecosystem functions. The exchange of both materials and energy is governed by the ecosystem services, which are diversified and complex (Song et al. 2015). Till date, valuation of whole ecosystem services is not distinguished and reported due to lack of appropriate data, effective methodology, and various limitations. However, Costanza et al. (2007; Costanza et al. 2014) have reported the valuations of major world's ecosystem services for marine and terrestrial ecosystems. The data on ecosystem service valuation affected by land use and land cover change may be useful in identifying and suggesting suitable land management options in the future and also help to distinguish the region most vulnerable to changes at landscape level. In this study, we hypothesize that land use and land cover change has affected the ecosystem services value (ESV) differently in different agro-climatic zones. The objective of this study was to asses LULC dynamics in the four agro-climatic zones of Odisha, eastern India using ancillary data to assess the ESV gained or lost due to LULC changes over spatial and temporal scales.

## Methodology

### Study area

The study area extended from 20.95° N latitude to 85.10° E longitude covering four major agro-climatic zones (ACZs), namely North Eastern Coastal Plain (NECP), North Central Plateau (NCP), North Eastern Ghat (NEG), and North-western Plateau (NWP) in

Odisha, an eastern state of India (Fig. 1). Four agro-climatic regions selected for this study represent distinct topography, climatic, vegetation, and biophysical characteristics. Rice is the major crop cultivated and consumed as a staple food in all of these four ACZs. The physiography and climatological parameters of these ACZs are presented in Table 1. One representative district from each ACZ was selected for the present study.

## Satellite data processing and land use classification

In this study, we used multispectral Landsat 5 TM satellite imagery for the years 1989, 1996, 2005, and 2011; whereas, Landsat 8 OLI imagery was used for the year 2016. The crop calendar for different ACZs of the study areas was studied, and satellite images were acquired coinciding with peak vegetative growth stage of crop in the *kharif* and *rabi* seasons. These satellite imageries were downloaded from the website *https://earthexplorer.usgs.gov/* (for details, see Table 2). All the satellite image processing including image enhancement and image classifications were done in ERDAS imagine 2014. ArcGIS 10 was used for preparing the land-use/land-cover maps.

## Image classification

The satellite images were classified into six land use and land cover (LULC) classes such as agricultural land (mono cropping and dual cropping), forest, waterbody, wasteland, and built-up and mining area (Table 3), using a decision tree classification technique (Punia et al. 2011). After classification, the classified maps were imported into ArcGIS 10.0 for calculating the area statistics of different land use types. Land use statistics was subsequently used for calculation of ecosystem service values of different land use types.

The percentage change (PC) and annual average % change (AAC) have been calculated by following formula:

$$PC = \{(Y_k - Y_1)/Y_1\} \times 100$$

$Y_1$ is taken as the base year, i.e., 1989 and $Y_k$ is the successive years taken for study, i.e., 1996, 2005, 2011, and 2016.

AAC = PC / difference between the year of study and base year.

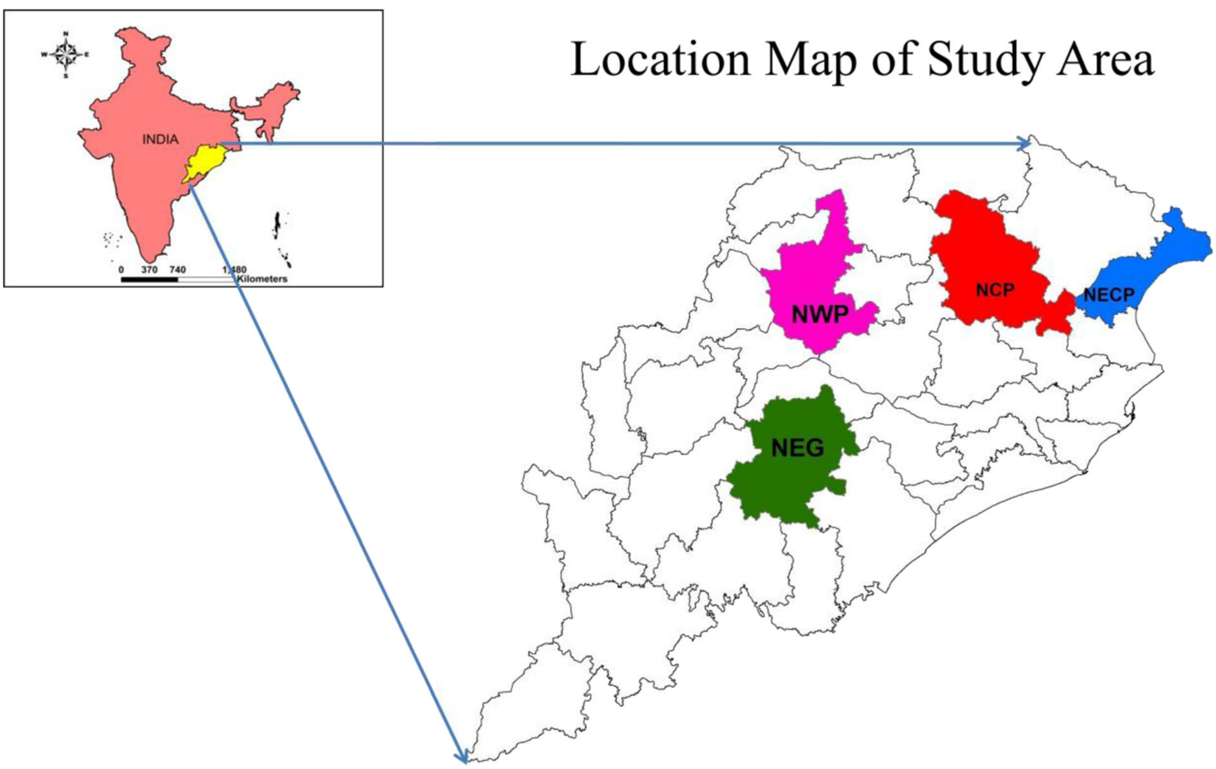


**Fig. 1** Study area showing four representative districts in four agro-climatic zones in Odisha, India

**Table 1** Physiography, climate, broad soil group, and cropping pattern of study area

| S. no. | Agro-climatic zone | Physiography | Climate | Broad soil group | Major crops |
|---|---|---|---|---|---|
| 1 | North Central Plateau (NCP) (Keonjhar) | Latitude, 21° 1′ N to 22° 10′ N; longitude, 85° 11′ E to 86° 22′ E<br>Forest, 37.34% of total area; land form: valleys and low land, mountainous highlands | Hot and moist, sub-humid; rainfall, 1534 mm; temp., 11.1–36.6 °C | Lateritic, red and yellow, mixed red and black | Rice, maize, till, niger, pigeon pea etc. |
| 2 | North-western Plateau (NWP) (Sambalpur) | Latitude, 20° 40′ N to 22° 11′ N; longitude, 82° 39′ E to 85° 15′ E<br>Forest, 54% of total area; land form: hilly terrain, plateau and ridges, valley and plains | Hot and moist, sub-humid; rainfall, 1600 mm; temp., 15.0–38.0 °C | Red, brown forest, red, and yellow, mixed red and black. | Rice, gram, pigeon pea, groundnut, sesame, mustard, caster, linseed, sugarcane etc. |
| 3 | North Eastern Coastal Plain (NECP) (Balasore) | Latitude, 20° 48′ N to 21° 59′ N; longitude, 86° 16′ E to 87° 29′ E<br>Forest, 8.66% of total area; land form: coastal plains, hilly terrains | Moist sub-humid; rainfall, 1568 mm; temp., 14.8–36.0 °C | Red, lateritic, deltaic alluvial, coastal alluvial, and saline. | Rice, pulses, groundnut, caster, mustard, linseed, etc. |
| 4 | North Eastern Ghats (NEG) (Kandhamal) | Latitude, 19° 34′ N to 20° 36′ N; longitude, 88° 34′ E to 84° 34′ E<br>Forest, 71.19% of total area; land form: hilly terrain with narrow valleys | Hot and moist, sub-humid; rainfall, 1597 mm, temp., 10.4–37.0 °C | Brown forest, lateritic alluvial, red, mixed red and black. | Rice, mustard, maize, niger, etc. |

Assessment of ecosystem service value

In this study, we have estimated the ecosystem service values which are associated with land use and land cover change. We have considered the ecosystem service functions of gas regulation, climate regulation, water supply, and soil formation, waste treatment, and food production, provision of raw materials and recreation value of different ecosystems such as agricultural land, forest, and waterbodies.

We have modified the methodology of Costanza et al. (2014) for valuation of the climate regulation function for agricultural land. In eastern India, the majority of the area is cultivated with rice as the principal crop (Panigrahy et al. 2010; Dhillon et al. 2010). Rice ecosystems act as a major greenhouse gas (GHG) emission sources due to emissions of $CO_2$, $CH_4$, and $N_2O$. Therefore, climate regulation (modified) was calculated by subtracting the GHG emissions from the carbon uptake by the system to get a net GHG balance for the agricultural land. The quantity of GHGs emitted from the rice fields annually was computed using a partial life cycle assessment (LCA) method as described by (Hillier et al. 2009; Yan et al. 2015; Dubey and Lal 2009). Then the carbon credit value of \$43/t C-equivalent (IPCC 2007) was used for converting the carbon credit into a monetary value.

We used the equation given by Xie et al. (2003) for calculating ecosystem service value coefficients for different LULC.

$$VC_{kf} = V_{\mathrm{F}} \times R_{kf} \quad (1)$$

Where, $VC_{kf}$ (US\$ per hectare per year) is the ecosystem service value for ecosystem function $f$ in land use type $k$. $V_{\mathrm{F}}$ is food production values of agriculture land per area per year, adopted from Costanza et al. (2014). $R_{kf}$ is the ratio of ecosystem service to food production values for function $f$ in land use type $k$.

The value of the food production service provided by agricultural lands per hectare per year was US\$ 2323. Costanza et al. (2014) was converted to a unit value for the determination of the production ratio. Finally, the value coefficients of ecosystem services were calculated by multiplying the total food production value of the selected study area by their service to production ratios.

**Table 2** Details of satellite data acquisition for different agro-climatic zones

| Districts | Path | Row | Date (Julian day) | |
|---|---|---|---|---|
| | | | Kharif | Rabi |
| Balasore | | | | |
| 1989 | 139 | 45 | 309 | 98 |
| 1996 | 139 | 45 | 294 | 70 |
| 2005 | 139 | 45 | 318 | 65 |
| 2011 | 139 | 45 | 271 | 79 |
| 2016 | 139 | 45 | 298 (2015) | 58 (2016) |
| Sambalpur | | | | |
| 1989 | 141 | 45 | 329, 336 | 73, 96 |
| 1996 | 141 | 45 | 317, 308 | 93, 84 |
| 2005 | 141 | 45 | 309, 316 | 56, 95 (2006) |
| 2011 | 141 | 45 | 310, 317 | 86, 93 |
| 2016 | 141 | 45 | 273, 312 (2015) | 75, 84 (2016) |
| Kandhamal | | | | |
| 1989 | 141, 140 | 46 | 336, 345 | 41, 48 |
| 1996 | 141, 140 | 46 | 317, 308 | 68,93 |
| 2005 | 141, 140 | 46 | 280, 287 | 72,76 |
| 2011 | 141, 140 | 46 | 310, 317 | 70,61 |
| 2016 | 141, 140 | 46 | 273, 294 (2015) | 91, 84 (2016) |
| Keonjhar | | | | |
| 1989 | 139, 140 | 45 | 306, 313 | 73, 98 |
| 1996 | 139, 140 | 45 | 294, 317 | 109, 86 |
| 2005 | 139, 140 | 45 | 318, 309 | 97,56 |
| 2011 | 139, 140 | 45 | 271, 310 | 79, 86 |
| 2016 | 139, 140 | 45 | 273, 298 (2015) | 84, 77 (2016) |

The values in parenthesis shows the year for which data was used

After calculating the ecosystem service value per unit area, the service value of each function was obtained for each LULC using Eqs. (2) and (3):

$$\mathrm{ESV}_k = \sum_f A_k \times \mathrm{VC}_{kf} \quad (2)$$

$$\mathrm{ESV}_f = \sum_k \mathrm{A}_k \times \mathrm{VC}_{kf} \quad (3)$$

$$\mathrm{ESV} = \sum_k \sum_f \mathrm{A}_k \times \mathrm{VC}_{kf} \quad (4)$$

where

$\mathrm{ESV}_k$ is the ecosystem service value of land use category "$k$".

$\mathrm{ESV}_f$ is the value of ecosystem service function type "$f$".

ESV is total ecosystem service value of the different land use classes of the study area.

$A_k$ is the area (hectare) of land use category "k".

## Results

### Changes in land use/land cover

The temporal land use and land cover maps at 5-year intervals from 1989 to 2016, selected from four agro-climatic zones, are presented in Fig. 2, and the areas under different land use/land cover classes are presented in Table 4.

It was estimated that NEG (Kandhamal district) had the highest (64.1%); whereas, NECP (Balasore) had lowest (9.5%) forest cover of total geographical area of the districts (Table 4). During the study period, an overall reduction of 5.2%, 13.7%, and 3.6% forest cover was recorded in NWP (Sambalpur), NCP (Keonjhar), and NEG (Kandhamal), respectively. Sambalpur and Balasore districts recorded a reduction of 9.1 and 16.7% of forest cover during 1989 to 2005, which increased by 4.3% and 23.6%, in the subsequent period

**Table 3** Description of land use and land cover classes

| Land cover type | Description |
|---|---|
| Monocropping | Single cropping rice, single cropping wheat |
| Dual cropping | Double cropping rice, pulses, oil seeds, vegetables |
| Forest | Tropical semi evergreen, tropical dry deciduous, tropical moist deciduous and littoral and swamp forest |
| Waterbodies | Reservoir, pond, lake, river, and stream |
| Wasteland | Land with/without shrub, waterlogged and marshy land, gullied and/or ravenous land (Medium), sand-coastal, barren rocky/stony waste |
| Built-up | Rural and urban area which densely covered by building and infrastructures. |
| Mining | Area where extraction of mineral, ore done through digging process. |

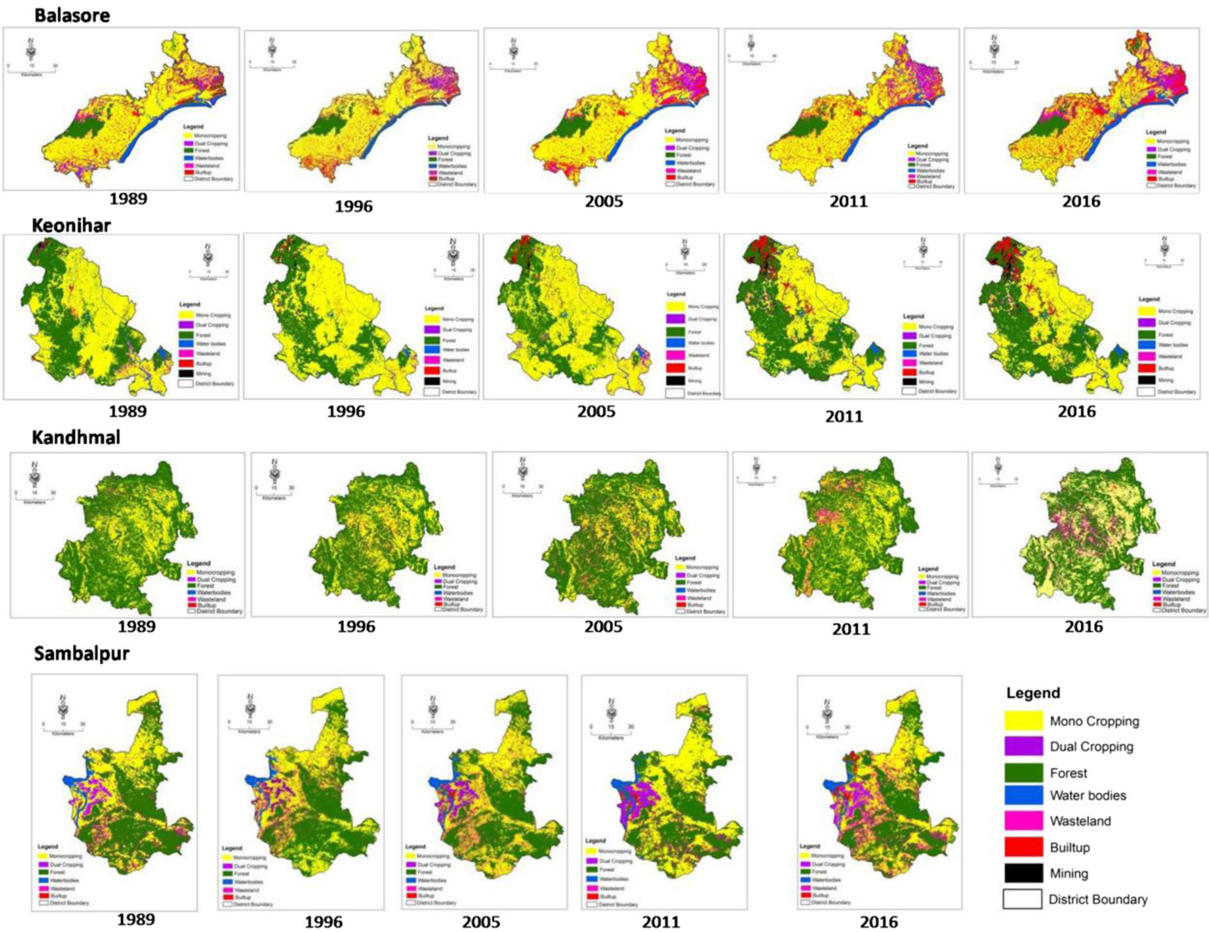


**Fig. 2** Land use and land cover classification of four districts of Odisha, India

from 2005 to 2016, respectively. The maximum reduction (13.7%) in forest cover among all the four districts was observed in Keonjhar, but the rate of decline of forest cover was maximum during 1996–2005 which was 5.94%. Mining is a prominent activity in Keonjhar which increased from 17 to 119 $km^2$ from 1989 to 2016.

There was a reduction in agricultural area during 1989 to 2016 in Balasore and Kandhamal districts, but the greatest reduction (17.2%) was recorded in Balasore (Table 4). Overall, there was an increase in agricultural area in Sambalpur and Keonjhar, by 3.7 and 2.6%, respectively, from 1989 to 2016. Although during 2005–2011, a decline in agricultural area was estimated across all districts, the highest decline (9.6%) was reported in Sambalpur. There was 4.4% decline in agricultural area in Kandhamal from 1996 to 2005.

Built-up land comprises rural, urban, and industrial areas. An overall increase in built-up areas was observed in all the four districts. The largest built-up area among the four districts was recorded in Balasore. The maximum rate (19.1%) of increase in built-up area per annum was reported for Kandhamal; whereas, the lowest rate (3.8%) was recorded for Keonjhar (Table 4). Compared to other study intervals, the increase in built-up area during 2011–2016 was highest in all the four districts. The highest per annum increase (56 $km^2$/annum) was recorded for Balasore; whereas, Kandhamal had the lowest rate of increase (3 $km^2$/annum). Keonjhar had the second highest rate of increase during 2011–2016, but during 1996–2005, it had the greatest rate of increase in built-up area.

**Table 4** Land use land cover change from 1989 to 2016

| | Agricultural land | | | Forest | | | Waterbody | | | Wasteland | | | Built-up | | | Mining | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LU ($km^2$) | PC | AAC (%) | LU ($km^2$) | PC | AAC (%) | LU ($km^2$) | PC | AAC (%) | LU ($km^2$) | PC | AAC (%) | LU ($km^2$) | PC | AAC (%) | LU ($km^2$) | PC | AAC (%) |
| Sambalpur | | | | | | | | | | | | | | | | | | |
| 1989 | 2678.9 | – | – | 3396.0 | – | – | 276.2 | – | – | 354.5 | – | – | 26.0 | – | – | – | – | – |
| 1996 | 2658.9 | −0.7 | −0.1 | 3326.1 | −2.1 | −0.3 | 292.4 | 5.8 | 0.8 | 399.0 | 12.6 | 1.8 | 55.3 | 112.8 | 16.1 | – | – | – |
| 2005 | 2999.5 | 12.0 | 0.7 | 3087.2 | −9.1 | −0.6 | 263.5 | −4.6 | −0.3 | 290.4 | −18.1 | −1.1 | 91.0 | 250.1 | 15.6 | – | – | – |
| 2011 | 2711.0 | 1.2 | 0.1 | 3211.2 | −5.4 | −0.2 | 293.5 | 6.3 | 0.3 | 416.4 | 17.5 | 0.8 | 99.5 | 282.7 | 12.9 | – | – | – |
| 2016 | 2778.8 | 3.7 | 0.1 | 3219.1 | −5.2 | −0.2 | 265.7 | −3.8 | −0.1 | 322.1 | −9.1 | −0.3 | 146.0 | 461.8 | 17.1 | – | – | – |
| Balasore | | | | | | | | | | | | | | | | | | |
| 1989 | 2873.1 | – | – | 356.9 | – | – | 164.9 | – | – | 55.4 | – | – | 404.6 | – | – | – | – | – |
| 1996 | 2810.7 | −2.2 | −0.3 | 353.1 | −1.1 | −0.2 | 160.1 | −2.9 | −0.4 | 44.5 | −19.7 | −2.8 | 486.0 | 20.1 | 2.9 | – | – | – |
| 2005 | 2756.8 | −4.0 | −0.3 | 297.5 | −16.7 | −1.0 | 166.9 | 1.2 | 0.1 | 53.7 | −3.2 | −0.2 | 580.1 | 43.4 | 2.7 | – | – | – |
| 2011 | 2675.6 | −6.9 | −0.3 | 345.4 | −3.2 | −0.1 | 191.0 | 15.8 | 0.7 | 55.1 | −0.6 | 0.0 | 587.9 | 45.3 | 2.1 | – | – | – |
| 2016 | 2378.0 | −17.2 | −0.6 | 367.6 | 3.0 | 0.1 | 188.2 | 14.1 | 0.5 | 54.8 | −1.2 | 0.0 | 866.4 | 114.1 | 4.2 | – | – | – |
| Kandhamal | | | | | | | | | | | | | | | | | | |
| 1989 | 2424.1 | – | – | 5362.4 | – | – | 48.4 | – | – | 210.9 | – | – | 11.7 | – | – | – | – | – |
| 1996 | 2502.0 | 3.2 | 0.5 | 5228.2 | −2.5 | −0.4 | 46.4 | −4.1 | −0.6 | 253.1 | 20.0 | 2.9 | 28.2 | 141.6 | 20.2 | – | – | – |
| 2005 | 2392.0 | −1.3 | −0.1 | 5211.9 | −2.8 | −0.2 | 50.9 | 5.1 | 0.3 | 351.9 | 66.8 | 4.2 | 51.2 | 339.2 | 21.2 | – | – | – |
| 2011 | 2389.4 | −1.4 | −0.1 | 5210.5 | −2.8 | −0.1 | 50.1 | 3.5 | 0.2 | 350.0 | 65.9 | 3.0 | 57.7 | 395.2 | 18.0 | – | – | – |
| 2016 | 2403.1 | −0.9 | 0.0 | 5168.0 | −3.6 | −0.1 | 53.0 | 9.5 | 0.4 | 362.2 | 71.7 | 2.7 | 71.7 | 515.3 | 19.1 | – | – | – |
| Keonjhar | | | | | | | | | | | | | | | | | | |
| 1989 | 3956.6 | – | – | 3617.4 | – | – | 194.2 | – | – | 303.0 | – | – | 211.5 | – | – | 17.3 | – | – |
| 1996 | 4055.4 | 2.5 | 0.4 | 3453.7 | −4.5 | −0.6 | 167.7 | −13.6 | −1.9 | 363.7 | 20.0 | 2.9 | 233.5 | 10.4 | 1.5 | 26.0 | 49.9 | 7.1 |
| 2005 | 4128.9 | 4.4 | 0.3 | 3248.5 | −10.2 | −0.6 | 194.5 | 0.2 | 0.0 | 334.8 | 10.5 | 0.7 | 361.4 | 70.9 | 4.4 | 31.9 | 84.0 | 5.3 |
| 2011 | 4009.6 | 1.3 | 0.1 | 3163.5 | −12.5 | −0.6 | 198.7 | 2.3 | 0.1 | 453.2 | 49.6 | 2.3 | 378.7 | 79.1 | 3.6 | 96.3 | 455.1 | 20.7 |
| 2016 | 4059.0 | 2.6 | 0.1 | 3122.0 | −13.7 | −0.5 | 196.8 | 1.4 | 0.1 | 403.9 | 33.3 | 1.2 | 429.7 | 103.1 | 3.8 | 118.7 | 584.2 | 21.6 |

(LU = land use, PC = percentage of change, AAC = annual average % change). PC and AAC are calculated by taking 1989 as base year

Change detection performed from 1989 to 2016 revealed that 177 and 32 $km^2$ was converted from forest and waste land, respectively, to agricultural (100 $km^2$) and built-up land (120 $km^2$) in Sambalpur. In Balasore, around 495.1 $km^2$ of agricultural area was converted to other land uses, mainly to built-up land (462 $km^2$). There was conversion of 495.4 $km^2$ from forest to other land uses in Keonjhar district.

### Ecosystem service values

The value of ecosystem services was calculated by accounting for the following ecosystem service functions: gas regulation, climate regulation, water supply, soil formation, waste treatment, food production, provision of raw material, and land for recreation, for agricultural land, forest, and waterbodies for 1989, 1996, 2005, 2011, and 2016 (Table 5).

The ESV of forests increased in all the four districts from 1989 to 2016. Over the 27 years, the maximum increase of about 131.9% was estimated for Balasore; whereas, the smallest increase (30.6%) was estimated for Keonjhar. However, in Balasore, an annual increase of 4.9% was reported, with the lowest annual increase (1.1%) reported for Keonjhar. The ESV from all the three LULC, i.e., forests, agriculture, and waterbodies initially decreased from 1989 to 1996 and then increased till 2016, for all of the districts except for Sambalpur, where the ESV of agricultural land decreased in 2011, before increasing again till 2016. Since Kandhamal has the largest share of its land under forest, hence recorded highest ESV from forest.

The ESV of waterbodies increased in all of the four districts from 1989 to 2016. The percentage change was highest (156.9%) over 27 year in Balasore and lowest (45.0%) in Sambalpur. The total ESV contribution from waterbodies is highest in Sambalpur and lowest in Kandhamal, irrespective of year of study (Table 6).

The ESV of agricultural land increased in all of the four districts from 1989 to 2016. Similar to the ESV from forests, the percentage change was highest (91.1% over 27 year and 3.4% annually) in Balasore, and lowest (57.1% or 2.1% annually) in Keonjhar (Table 6).

The changes over study period (with fitted linear regression lines) in different ecosystem service functions like gas regulation, climate regulation, water supply, soil formation, waste treatment, food production, raw material, and recreation were plotted for the four ACZs in Fig. 3. All the ecosystem service functions had a positive slope indicating an improving trend over the years (Fig. 3). Similarly, the slope of ESV plotted over the time period showed a positive trend for the four ACZs. Highest positive slope was recorded for Kandhamal district where as lowest slope value was recorded for Sambalpur (Fig. 4). Among the three land use types, agricultural land provided highest ESV followed by forests and waterbodies, except for Kandhamal, where the ESV from forest was highest followed by agricultural land and waterbodies. Ecosystem service delivery per unit area followed the order as waterbody > agricultural land > forest (Table 7).

### Service function

The overall ranking for the study period were estimated based on the average impact of individual ESVs on total ESVs. These impacts from high to low are food production, climate regulation, recreation, waste treatment, soil formation, water supply, raw material, gas regulation (Table 8). Climate regulation and food production made the largest contribution (61%) to total ESVs. Averaging over all the four districts, the food production had the highest ESV, followed by climate regulation, irrespective of the year of study.

## Discussion

### Land use land cover change

The decline in forest cover in Sambalpur, Keonjhar, and Kandhamal during 1991–2015 is supported by the data from Forest Survey of India (FSI) by using a forest cover change matrix based on satellite imagery in which decrease of 45.7%, 14.0%, and 9.8% were reported. Increase of 2.4% and 19% were reported by FSI in the forest area of Sambalpur and Balasore, respectively, during 2005–2015, which is similar to our estimates. The reduction of forest area in Keonjhar was due to clearing of 35% of forest up to 2006 (Patra and Sethy 2014) for diverting forest land into mining activities for extraction of mineral ores. This is supported by the fact that 119 mines were operating at Keonjhar up to December 2006 (Patra et al. 2008; Patra and Sethy 2014; Dash 2007). Decreasing forest cover during 1989–2005 may be attributed to shifting cultivation, because Odisha

**Table 5** ESVs associated with ecosystem service functions (US$$10^5$, with 1989 as the base year)

| ES | 1989 | | 1996 | | 2005 | | 2011 | | 2016 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ESVs | % Share | ESVs | % Share | ESVs | % Share | ESVs | % Share | ESVs | % Share |
| Sambalpur | | | | | | | | | | |
| GR | 4.4 | 0.2 | 3.6 | 0.2 | 4.3 | 0.2 | 4.4 | 0.2 | 6.3 | 0.2 |
| CR | 821.4 | 31.7 | 660.7 | 31.0 | 818.2 | 28.9 | 786.5 | 29.7 | 1183.5 | 30.6 |
| WS | 179.0 | 6.9 | 151.1 | 7.1 | 205.3 | 7.2 | 192.6 | 7.3 | 272.4 | 7.0 |
| SF | 158.6 | 6.1 | 131.2 | 6.2 | 191.2 | 6.8 | 168.3 | 6.4 | 247.1 | 6.4 |
| WT | 185.7 | 7.2 | 154.8 | 7.3 | 210.4 | 7.4 | 195.9 | 7.4 | 281.2 | 7.3 |
| FP | 746.3 | 28.8 | 617.3 | 29.0 | 888.2 | 31.4 | 788.9 | 29.8 | 1156.2 | 29.9 |
| RM | 93.9 | 3.6 | 77.4 | 3.6 | 106.9 | 3.8 | 97.7 | 3.7 | 142.6 | 3.7 |
| R | 405.1 | 15.6 | 335.5 | 15.7 | 407.6 | 14.4 | 412.2 | 15.6 | 583.1 | 15.1 |
| Total | 2594.3 | 100.0 | 2131.6 | 100.0 | 2832.1 | 100.0 | 2646.5 | 100.0 | 3872.4 | 100.0 |
| Balasore | | | | | | | | | | |
| GR | 0.3 | 0.03 | 0.3 | 0.03 | 0.4 | 0.03 | 0.7 | 0.03 | 0.8 | 0.04 |
| CR | 98.2 | 8.9 | 77.6 | 8.3 | 137.8 | 8.9 | 207.4 | 9.9 | 246.6 | 11.2 |
| WS | 116.3 | 10.5 | 98.5 | 10.5 | 164.4 | 10.6 | 224.3 | 10.7 | 233.9 | 10.7 |
| SF | 122.4 | 11.0 | 103.8 | 11.1 | 171.2 | 11.1 | 224.8 | 10.7 | 228.3 | 10.4 |
| WT | 106.6 | 9.6 | 90.3 | 9.7 | 149.3 | 9.6 | 201.3 | 9.6 | 208.7 | 9.5 |
| FP | 540.0 | 48.7 | 457.9 | 49.0 | 754.2 | 48.7 | 992.4 | 47.4 | 1009.8 | 46.0 |
| RM | 52.6 | 4.7 | 44.6 | 4.8 | 73.2 | 4.7 | 96.8 | 4.6 | 99.2 | 4.5 |
| R | 72.0 | 6.5 | 61.1 | 6.5 | 98.4 | 6.4 | 146.8 | 7.0 | 165.6 | 7.6 |
| Total | 1108.6 | 100.0 | 934.2 | 100.0 | 1548.9 | 100.0 | 2094.6 | 100.0 | 2192.9 | 100.0 |
| Kandhamal | | | | | | | | | | |
| GR | 6.8 | 0.2 | 4.3 | 0.2 | 5.0 | 0.2 | 8.7 | 0.2 | 10.9 | 0.2 |
| CR | 1257.6 | 41.2 | 789.9 | 40.4 | 919.6 | 40.9 | 1613.4 | 41.0 | 2010.9 | 40.9 |
| WS | 127.5 | 4.2 | 83.8 | 4.3 | 95.1 | 4.2 | 165.8 | 4.2 | 209.5 | 4.3 |
| SF | 144.7 | 4.7 | 96.0 | 4.9 | 107.6 | 4.8 | 187.7 | 4.8 | 236.5 | 4.8 |
| WT | 175.0 | 5.7 | 113.7 | 5.8 | 129.7 | 5.8 | 226.2 | 5.8 | 284.1 | 5.8 |
| FP | 711.5 | 23.3 | 469.3 | 24.0 | 528.2 | 23.5 | 921.5 | 23.4 | 1159.3 | 23.6 |
| RM | 104.1 | 3.4 | 67.5 | 3.5 | 76.9 | 3.4 | 134.2 | 3.4 | 168.1 | 3.4 |
| R | 525.2 | 17.2 | 330.9 | 16.9 | 385.9 | 17.2 | 673.4 | 17.1 | 839.1 | 17.1 |
| Total | 3052.4 | 100.0 | 1955.5 | 100.0 | 2248.0 | 100.0 | 3931.0 | 100.0 | 4918.5 | 100.0 |
| Keonjhar | | | | | | | | | | |
| GR | 3.9 | 0.1 | 2.5 | 0.1 | 3.1 | 0.1 | 3.7 | 0.1 | 5.1 | 0.1 |
| CR | 794.3 | 29.1 | 501.5 | 27.8 | 631.1 | 26.8 | 761.0 | 26.9 | 1063.1 | 26.8 |
| WS | 184.1 | 6.7 | 122.4 | 6.8 | 167.3 | 7.1 | 201.4 | 7.1 | 283.1 | 7.1 |
| SF | 195.4 | 7.1 | 133.7 | 7.4 | 179.4 | 7.6 | 214.1 | 7.6 | 302.2 | 7.6 |
| WT | 197.9 | 7.2 | 132.1 | 7.3 | 176.6 | 7.5 | 211.8 | 7.5 | 297.2 | 7.5 |
| FP | 900.6 | 32.9 | 614.2 | 34.1 | 821.1 | 34.8 | 980.2 | 34.6 | 1381.8 | 34.8 |
| RM | 106.1 | 3.9 | 71.4 | 4.0 | 94.2 | 4.0 | 112.5 | 4.0 | 157.9 | 4.0 |
| R | 351.8 | 12.9 | 223.7 | 12.4 | 286.1 | 12.1 | 344.3 | 12.2 | 475.4 | 12.0 |
| Total | 2734.2 | 100.0 | 1801.6 | 100.0 | 2359.0 | 100.0 | 2829.1 | 100.0 | 3965.7 | 100.0 |

ESV, ecosystem service value; GR, gas regulation; CR, climate regulation; SF, soil formation; WS, water supply; WT, waste treatment; FP, food production; RM, raw materials; R, recreation had the largest area under shifting cultivation in India, with an annual area of 5298 km$^2$ of forest land converted for this purpose. These cultivation systems were dominant in tribal dominated districts, such as Kandhamal, Koraput, and Sambalpur (Ranjan and Upadhyay 1999).

The agricultural land use change pattern can be attributed to many factors such as urban growth, industrialization, and conversion to other land use classes. Effect of urbanization and industrialization are known to be key contributors to the loss of agricultural land (Satterthwaite et al. 2010). In Odisha, the industrial revolution took place starting from 1984 to 1985 up to 2012–2013, and this may have led to a loss of agricultural land (MSME report, 2016–2017). In Balasore, it has been reported that the area of the fish farming zone increased from 6.3 to 13.7% during 1973–2010 (Barman et al. 2015).

### Built-up land

Land use and land cover changes have strong impacts on soil, water quality and biodiversity which have direct consequences on natural resources (Kilic et al. 2006). LULC changes are dynamic and non-linear in nature. The conversion from one land to another shows different patterns depending on whether it is driven by natural or anthropogenic factors like increase in urbanization (Meshesha et al. 2014).

Many studies have reported conversion of agricultural land to human habitation due to the growth of large

**Table 6** Ecosystem service value of four agro- climatic zones of eastern India from 1989 to 2016

| ESV ($10^5$US$) | Agricultural land | | | Forest | | | Waterbody | | |
|---|---|---|---|---|---|---|---|---|---|
| | ESV ($10^5$US$/year) | PC | AAC (%) | ESV ($10^5$US$/year) | PC | AAC (%) | ESV ($10^5$US$/year) | PC | AAC (%) |
| Sambalpur | | | | | | | | | |
| 1989 | 1174.8 | – | – | 1231.4 | – | – | 148.6 | – | – |
| 1996 | 958.8 | − 18.4 | − 2.6 | 1006.2 | − 18.3 | − 2.6 | 131.3 | − 11.7 | − 1.7 |
| 2005 | 1432.7 | 22.0 | 1.4 | 1213.1 | − 1.5 | − 0.1 | 153.7 | 3.4 | 0.2 |
| 2011 | 1249.7 | 6.4 | 0.3 | 1224.0 | − 0.6 | 0.0 | 166.0 | 11.7 | 0.5 |
| 2016 | 1877.0 | 59.8 | 2.2 | 1758.9 | 42.8 | 1.6 | 215.5 | 45.0 | 1.7 |
| Balasore | | | | | | | | | |
| 1989 | 955.4 | – | – | 96.0 | – | – | 65.8 | – | – |
| 1996 | 807.8 | − 15.5 | − 2.2 | 82.3 | − 14.3 | − 2.0 | 55.4 | − 15.8 | − 2.3 |
| 2005 | 1359.2 | 42.3 | 2.6 | 116.6 | 21.5 | 1.3 | 97.1 | 47.4 | 3.0 |
| 2011 | 1794.9 | 87.9 | 4.0 | 183.1 | 90.8 | 4.1 | 150.3 | 128.3 | 5.8 |
| 2016 | 1826.2 | 91.1 | 3.4 | 222.6 | 131.9 | 4.9 | 169.1 | 156.9 | 5.8 |
| Kandhamal | | | | | | | | | |
| 1989 | 1088.2 | – | – | 1915.3 | – | – | 25.6 | – | – |
| 1996 | 711.7 | − 34.6 | − 4.9 | 1204.2 | − 37.1 | − 5.3 | 15.9 | − 38.2 | − 5.5 |
| 2005 | 801.1 | − 26.4 | − 1.6 | 1403.9 | − 26.7 | − 1.7 | 20.3 | − 20.7 | − 1.3 |
| 2011 | 1422.9 | 30.8 | 1.4 | 2450.9 | 28.0 | 1.3 | 35.0 | 36.4 | 1.7 |
| 2016 | 1802.3 | 65.6 | 2.4 | 3047.5 | 59.1 | 2.2 | 46.4 | 80.8 | 3.0 |
| Keonjhar | | | | | | | | | |
| 1989 | 1501.5 | – | – | 1104.4 | – | – | 88.0 | – | – |
| 1996 | 1005.7 | − 33.0 | − 4.7 | 705.3 | − 36.1 | − 5.2 | 50.8 | − 42.2 | − 6.0 |
| 2005 | 1371.9 | − 8.6 | − 0.5 | 875.4 | − 20.7 | − 1.3 | 77.8 | − 11.6 | − 0.7 |
| 2011 | 1652.9 | 10.1 | 0.5 | 1047.7 | − 5.1 | − 0.2 | 97.6 | 11.0 | 0.5 |
| 2016 | 2359.3 | 57.1 | 2.1 | 1442.2 | 30.6 | 1.1 | 134.9 | 53.4 | 2.0 |

(ESV, ecosystem service value; LU, land use; PC, percentage of change; AAC, annual average % change)

PC and AAC are calculated by taking 1989 as base year

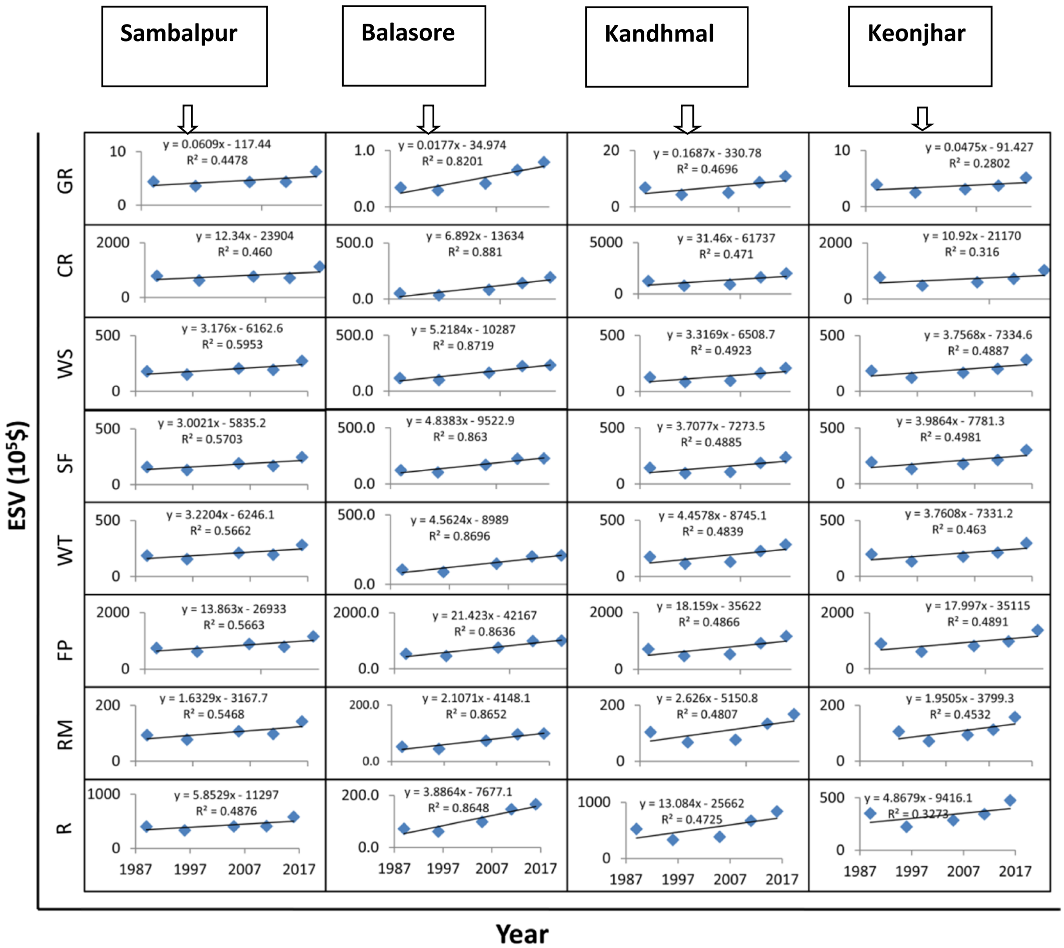


**Fig. 3** Slope of different ecosystem service functions of four agro-climatic zones over study periods. (ESV, ecosystem service value; GR, gas regulation; CR, climate regulation; SF, soil formation, WS, water supply; WT, waste treatment, FP, food production, RM, raw materials, R, recreation)

towns and cities in the developing world driven by high rates of population growth mostly without planning and uncontrolled urban expansion (Fazal 2000; Su et al. 2014).

In the Balasore region, major cities like Remuna, Soro etc., have expanded over the study period, and this is confirmed by increasing population density (Census of India 2011) as well as area statistics from satellite interpreted data reported by NRSC in 2005–2006 and 2011–2012 (NRSC 2011). In Sambalpur district, the increasing built-up area is supported by the MSME report for 2016–2017. Urban development increased greatly in Sambalpur district, mainly in Burla town over the decades 1951 to 2011, with a growth rate of 27.1% over the period (Bag 2015).

## Ecosystem services of forests, agriculture, and waterbodies

As seen in the LULC statistics, forest cover, and hence the ecosystem services provided by forests, decreased from 1989 to 1996. But thereafter, forest cover increased in almost all the studied ACZs and hence ecosystem services also increased from 1996 onwards. The decrease in ESV associated with decrease in forest cover is supported by other studies (Kreuter et al. 2001) who found that anthropogenic factors like mining activity, built-up land, deforestation, industry stabilization and jhum cultivation play an important role in forest cover loss, which has directly or indirectly resulted in a decrease in ESV of forests over the study period.

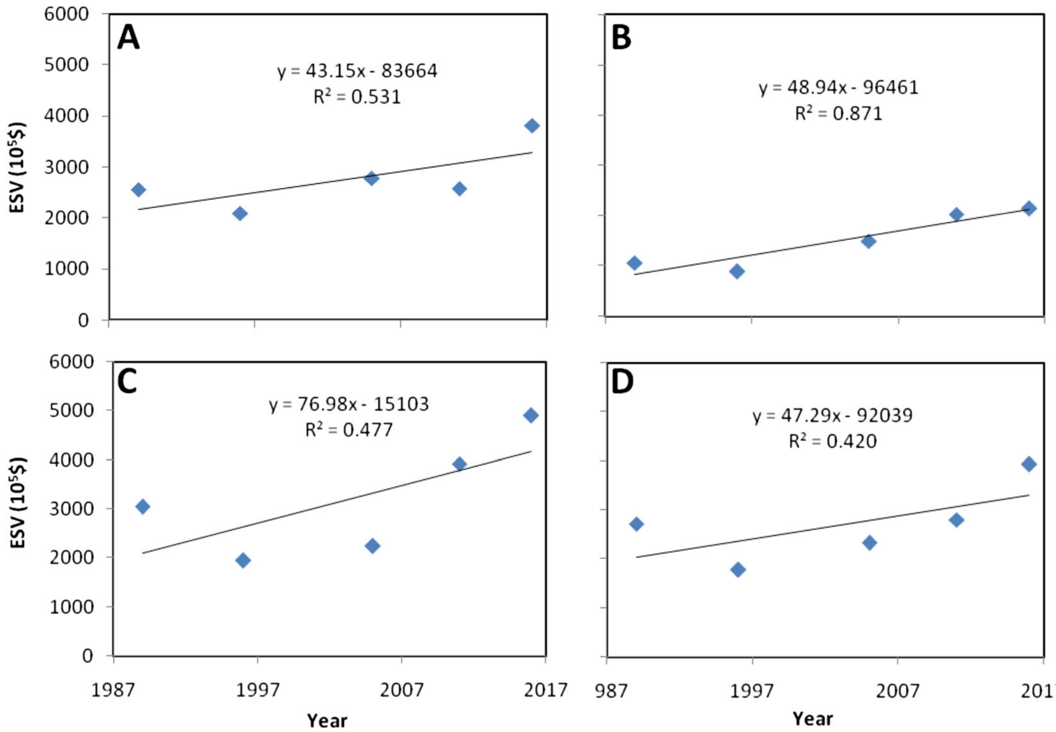


**Fig. 4** Slope of total ecosystem service value (ESV) over the study period (1989–2016) (**a** Sambalpur; **b** Balasore; **c** Kandhamal; **d** Keonjhar)

Higher values of ESV from forest cover in Kandhamal compared to other districts was due to large forest cover area, which was approximately 60% of the total geographical area (FSI 2015).

The low ESV for agricultural land during 1996 may be attributed to the low crop production due to drought in Odisha in which there was 34% less rainfall than the long-term average (Directorate of Agriculture, Govt. of Odisha 2008–2009). During 1996–1997, around 28 districts of Odisha were affected by severe drought and a loss of 93.3% of crop harvest was reported (Jena 2018). The highest ESV from agricultural land compared to other land uses may be due to higher area as well as the ecosystem service coefficients. Less ESV in 2011 compared to 2005 in Sambalpur may be attributed to low productivity of crops. According to the India Disaster Management Report 2011, 9 blocks and 525 villages in Sambalpur district were affected by flood which resulted in low productivity of crops in that year.

The reason behind the increasing ESVs in this study for three land use classes over the years may be increasing agricultural productivity (Directorate of agriculture and food production, Odisha 2014-15). In contrast to our study, other researchers (Yoshida et al. 2010; Li et al. 2014) reported declining trend of ESVs over the years. A decline ESVs may depend upon many other factors like decreasing land use area, and the coefficient values of ecosystem service functions (Kindu et al. 2016). The decreasing ESVs over the year may be due to use of high quantity of fertilizer, pesticides etc. Over use of fertilizer and pesticides can deteriorate the soil quality and ultimately lead to ecological imbalance, and hence decreased ESV (Isbell et al. 2013). In comparison to the study area where average fertilizer consumption is 62.6 kg ha$^{-1}$ (Directorate of economics and statistics 2016), the Indian average is 130.7 kg ha$^{-1}$; whereas, other countries like China (424.4 kg ha$^{-1}$), New Zealand (1485.4 kg ha$^{-1}$) and many other developing and developed country use much higher fertilizer application rates (Directorate of Economics and Statistics 2016). Similarly, pesticide consumption in India is the lowest (0.6 kg ha$^{-1}$) against China (13 kg ha$^{-1}$), Taiwan (17 kg ha$^{-1}$), and Japan (12 kg ha$^{-1}$) (FICCI 2016). In the study area, only 0.115 kg ha$^{-1}$ of pesticides was used which is lower than the Indian average pesticide use (Odisha Economic Survey 2016–2017). This could

Table 7 Ecosystem service value of four agro-climatic zones of eastern India from 1989 to 2016

| Agro-climatic zones | Years | Unit value of ESV (US$ $ha^{-1}$ $yr^{-1}$) | | | |
|---|---|---|---|---|---|
| | | Agricultural land | Forest | Waterbody | Total |
| Sambalpur | 1989 | 439 | 363 | 538 | 1339 |
| | 1996 | 361 | 303 | 449 | 1112 |
| | 2005 | 478 | 393 | 583 | 1454 |
| | 2011 | 461 | 381 | 566 | 1408 |
| | 2016 | 675 | 546 | 811 | 2033 |
| Balasore | 1989 | 333 | 269 | 399 | 1001 |
| | 1996 | 287 | 233 | 346 | 866 |
| | 2005 | 493 | 392 | 582 | 1467 |
| | 2011 | 671 | 530 | 787 | 1988 |
| | 2016 | 768 | 605 | 898 | 2272 |
| Kandhamal | 1989 | 449 | 357 | 530 | 1336 |
| | 1996 | 284 | 230 | 342 | 857 |
| | 2005 | 335 | 269 | 400 | 1004 |
| | 2011 | 595 | 470 | 698 | 1764 |
| | 2016 | 750 | 590 | 875 | 2215 |
| Keonjhar | 1989 | 379 | 305 | 453 | 1138 |
| | 1996 | 248 | 204 | 303 | 755 |
| | 2005 | 332 | 269 | 400 | 1002 |
| | 2011 | 412 | 331 | 491 | 1235 |
| | 2016 | 581 | 462 | 686 | 1729 |

ESV, ecosystem service value

contribute to declining ESVs in developed countries as suggested by Isbell et al. (2013), since ecosystem productivity declines over time by over addition of nutrients, which lead to a loss of biodiversity. The reason for increasing ESV over the years in all the four contrasting agro-climatic zones in eastern India, despite mining activity in Keonjhar, may be due to less use of fertilizers and pesticides, coupled with technological advancement in agriculture, increasing trends of farm mechanization and introduction of high-yielding varieties etc. (Patra 2015 and Mohanty 2016).

The ESV of waterbodies per unit area was highest compared to agricultural land and forest. This was similar to the findings of Long et al. (2014). Similarly, other researchers (Li et al. 2017; Fu et al. 2016) also reported highest ESV per unit area for waterbody, followed by forest and agricultural land. The waterbodies of Sambalpur provides the highest ESV compared to other regions, which may be due to the presence of the Hirakud dam, that generates 347.5 MW electricity (Raje and Mujumdar 2010), as well as supporting 12 industrial units by providing water for various industrial processes. There is under-utilization of water resources in the study area and there is more scope for utilizing these natural resources for aquaculture, pisciculture and other integrated farming system models, which may further enhance the ESV of these waterbodies, though if biodiversity were included as an indicator, these activities could reduce ESV. In this study, forest area was used for estimating the ESV rather than biodiversity values and this may be the reason why the unit value of forest was lowest as compared to waterbody and agricultural land. If biodiversity values were considered, forest might have recorded highest value than other two classes which is reported in many other studies (Liu et al. 2012: Zhang et al. 2015).

Assessing ecosystem services due to land use and land cover changes at different spatial and temporal scales will help in identifying the sustainable

Table 8 Analysis of rank of ecosystem service ($10^5$US$/year) function over study periods

| Ecosystem service value | 1989 | 1996 | 2005 | 2011 | 2016 | Rank |
|---|---|---|---|---|---|---|
| Food production | 724.6 | 539.7 | 747.9 | 920.8 | 1176.8 | 16.7 |
| Climate regulation | 719.3 | 485.5 | 610.4 | 835.5 | 1114.1 | 14.6 |
| Recreation | 338.5 | 237.8 | 294.5 | 394.2 | 515.8 | 6.6 |
| Waste treatment | 166.3 | 122.7 | 166.5 | 208.8 | 267.8 | 3.8 |
| Soil formation | 155.3 | 116.2 | 162.3 | 198.7 | 253.5 | 3.6 |
| Water supply | 151.7 | 114.0 | 158.0 | 196.0 | 249.7 | 3.6 |
| Raw materials | 89.2 | 65.2 | 87.8 | 110.3 | 142.0 | 2.0 |
| Gas regulation | 3.9 | 2.7 | 3.2 | 4.4 | 5.8 | 0.1 |

management practices such as ecological intensification of high-yielding cereal-based cropping systems, conservation agriculture for increasing resource use efficiency through real-time application of fertilizers and water use for sustainable ecosystem biodiversity in the region.

## Conclusion

In this study, land use and land cover was estimated using LANDSAT data for 1989, 1996, 2005, 2011, and 2016 and ecosystem service values were calculated for agricultural land, waterbodies, and forest. There was reduction of 5.2%, 13.7%, and 3.6% in forest cover in Sambalpur, Keonjhar, and Kandhamal respectively during 1989–2016. Reduction in agricultural area was observed mainly due to conversion of agricultural areas into built-up areas particularly in fast growing districts such as Balasore where a 17.2% reduction was observed during 1989 to 2016, with an increase in built-up areas in the study area. The ESV of agricultural land increased in all the four districts from 1989 to 2016. Similar to ESV from forests, percentage change was highest (91.1% or 3.4% annually) in Balasore and lowest (57.1% or 2.1% annually) in Keonjhar in agricultural land. Total ESV contribution from waterbodies was highest in Sambalpur and lowest in Kandhamal, irrespective of year of study. There were increasing ESVs in different agro-climatic zones in this study, which may be due to increasing productivity over the years by utilizing modern agricultural practices in recent years. All the ecosystem service functions showed a positive slope over the study period, indicating improving trends over time. The overall ranking for the study period was estimated based on the average impact of individual ESVs on total ESVs. These impacts from high to low are food production, climate regulation, recreation, waste treatment, soil formation, water supply, raw material, gas regulation. We emphasize the need to assess the change in ecosystem services due to land use and land cover change at regular intervals at different spatial and temporal scales, to track progress and to inform land use and land management policy.

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