

## Chapter 2

# A Case Study on Estimating the Ecosystem Service Values (ESVs) Under Anthropogenic Influences for Chennai and Hyderabad



Sudardeva and Manali Pal

**Abstract** Ecosystem services are inevitable to all biota on the earth and possess a value of approximately 125 trillion USD. Although the complete valuation of ecosystem services in monetary terms is uncertain, they are sine qua non to frame policies regarding the utilization of resources in a sustainable way. Moreover, the continuous urban growth imparts variations to the urban ecological land use and land cover (LULC) and urban ecosystem functions that possess serious challenges. However, studies on quantifying ecosystem services and assessing them under anthropogenic influence are scarce, especially for the metropolitans in India. In this scenario, we selected Chennai metropolitan area (CMA) and the Greater Hyderabad Municipal Corporation (GHMC), two rapidly urbanizing metropolitan areas with increasing anthropogenic activities observed since last decade, for quantifying the ecosystem service value (ESV). The study applied the approach proposed by Costanza R et al. (Nature, 1997;387:253–260) that uses the spatiotemporal variations of LULC to compute the ESV. The LANDSAT data products are used to generate LULC for the CMA and GHMC for each decade since 1995–2022 (to mark the economic transition for the country), for example, for the years 1995, 2005, 2015 and 2022. The study reveals the drastic changes in the area of individual classes. Vegetation has shrunk noticeably between 1995 and 2022, followed by waterbodies for both the areas. Due to urbanization, the builtup is found to be increased in an unregulated way that reduces ESV. The substantial loss in ESV questions the resilience of the study areas, and this trend continues till the end of the observation period. The findings summarize the loss in ecosystem services that need urgent measures to be taken to enhance the urban ecosystem sustainability through the restoration of waterbodies and effective land management practices.

**Keywords** Ecosystem services · Ecosystem functions · Ecosystem service values · Anthropogenic activities · Urbanization

---

Sudardeva · M. Pal (✉)

Department of Civil Engineering, NIT, Warangal, Telangana, India

## 2.1 Introduction

The ecosystem is a biophysical system, defined by the complex interaction of biotic and abiotic components in a physical environment to form a new bubble in life form. The interdependency of biotic components among themselves and with the abiotic components defines the behaviour of a biological organism in the ecosystem. The behaviour of these components results in ecosystem functioning through which ecosystem services are derived in the form of goods and services. These ecosystem services (ES) are inevitable for the existence of life forms; they are direct and indirect benefits drawn from nature and enjoyed by humans for their livelihood. Even though all biotic components influence ecosystem functioning, human beings influence the system on a greater scale due to the large-scale utilization of services offered by the ecosystem. Hence, the quantification of the association between rapid urban growth and ecosystem services plays an essential role for the urban sustainability and development related to planning and policies. A study by Costanza et al. (1997) listed 17 ecosystem services that are derived from a single or a combination of two or more ecosystem functions. Another study by Rudolf S. de Groot categorized ecosystem functions into the regulation function (maintenance of essential ecological process and life support system), habitat functions (providing habitat for plants and animal species), production functions (provision of natural resources) and information functions (providing opportunities for evolution). The definitions of individual ecosystem services offered under each categorization are as follows:

1. **Regulation functions:** Those functions which regulate the essential ecosystem process through which basic life system is supported are termed as regulation functions. The services that are derived from bio-geochemical cycles and other bio-spheric processes to the ecosystem include gas regulation, climate regulation, disturbance prevention, water regulation, water supply, soil formation, soil retention, nutrient regulation, waste treatment, pollination and biological control.
2. **Habitat functions:** The ecosystem services that enable the life forms to get habituated with normal living in order to reproduce and proliferate among themselves such that there is a conservation in biodiversity and genetic diversity are known to as habitat functions.
3. **Production functions:** The livelihood of human is supported by intake of biomass which is a direct result of synthesis from primary producers and secondary producers. They include food, raw materials, genetic resources, medicinal resources and ornamental resources.
4. **Information functions:** These functions provide essential reference function that is transferred as information to humans in the process of evolution. The services generated provide values to life and help us in understanding the need for existence of ecosystem. They include recreation, aesthetic information, cultural and artistic information, spiritual and historic information, science and education.

The above listed services may not be able to catalogue all the ecosystem services, since there are a lot of unidentified benefits used by human in the ecosystem. The

dynamics of ecosystem along with the human influence urges us to look into the idea of ecosystem sustainability. To implement them in the society, the resources and services availed so far have to be utilized in a sustainable manner. There is a need for an account of the ecosystem services in terms of monetary value for prioritising human made decisions over development and conservation. The value of the world's ecosystem services and natural capital are estimated based on willingness to pay by the resource utilizers (Costanza et al. 1997, 2008, 2014). The study by De Groot et al. (2002, 2010, 2012) and by Kreuter et al. (2001), Liu et al. (2012) created ecosystem service valuation database by analysing the previous work on the valuation in monetary terms. The values of ecosystem services are updated from his earlier work by Costanza et al. (2011), considering consumer price index, and provided the factor of conversion as 1.38 from the year 1997 to 2011. A limited number of studies have been found on this problem statement, particularly for India, and the examples are as follows: Das and Das (2019) studied the impacts of urbanization and its dynamics on ecosystem services for Malda town in West Bengal, India. Sannigrahi et al. (2019) assessed the spatiotemporal variation in ESV for a natural reserve Sundarbans region, derived from spatiotemporal data of land use and land cover (LULC). Hence the valuation of ecosystem services depends on LULC Sannigrahi et al. (2020a, 2020b), and Sannigrahi et al. (2017, 2019) compared different supervised machine learning classification techniques to derive ecosystem service values (ESVs).

The study aims to present the trend in LULC of each category for a period of four decades (1995–2022) since the introduction of major economic reforms (1991) in India (Vikramani 2006). The change in the area occupied by each ecosystem class significantly impacts the functioning of the ecosystem, which further affects the extraction of ecosystem services. The more the natural element persists in the ecosystem, the least it is disturbed. But the needs of humans heavily influence LULC. It is essential to view and plan developmental initiatives in a sustainable way that alters the ecosystem of an urban area such that it should be a balance between resource utilization and extraction of ecosystem services. The study will state the current state of ecosystem functions and ESV derived from LULC. It will aid us to formulate indices that will help the local government to monitor and frame policies to achieve Sustainable Development Goal (SDG) concerning the urban area to make cities and human settlements inclusive, safe, resilient and sustainable. Furthermore, the change in LULC deteriorates the ecosystem and makes them prone to hazards. Since the increase in builtup area is associated with the increase in population, which in turn results in increase in demand of resources of water and energy, this additional demand in the existing system increases the stress on groundwater through extensive drafting, thus resulting in reduced baseflow component of the stream and may disturb the perennial nature of the stream. Additionally, the relationship between builtup and impervious surfaces is related to the increase in flood scenarios and land surface temperature (LST) that can affect the hydrological extremes. The valuation of ES would help in framing policy in an urban area for sustainable land use management practices. However, as mentioned earlier, the studies concerning the assessment of ES for urban region in India are limited.

Hence, this study has taken up to estimate the ESV for two metropolitans, namely, the Greater Hyderabad Municipal Corporation (GHMC) and Chennai Metropolitan Area (CMA) which has undergone rapid unregulated urbanization. The major objectives of the study are as follows:

1. To investigate the changes in LULC due to urbanization for the study area, that is, GHMC and CMA, over the last two decades, that is, 1995–2022
2. To estimate and detect the trends in ESVs offered by individual LULC classes and individual ecosystem functions

## **2.2 Rational of the Study**

Industrialization and its associated urbanization have made lives of human being more comfortable than ever before, and they significantly impacted human way of consuming and utilizing resources. This anthropogenic utilization has brought severe degradation of the ecosystem and reduced the services offered by the ecosystem (Chopra et al. 2022). Since this is the age of sustainable development, a prior knowledge on services offered by the ecosystem is needed to draft policies for optimal and environment-friendly utilization of resources. This study attempts to estimate the ecosystem service values of two Indian metropolises and analyse the trend in the services between two decades, that is, 1995–2022. It also attempts to highlight the impacts of change in LULC triggered by economic opportunities on ecosystem service values.

## **2.3 Limitation of the Study**

Valuation of ecosystem services involves the process of identifying the ecosystem services and assigning a monetary value to them. This study considers only a list of 17 ecosystem services based on a study performed by Costanza et al. (1997). The study excludes some of the services from the process limiting the idea of valuing the entire ecosystem. The values of ecosystem services are considered in terms of US Dollar (USD) and are not converted to Indian Rupee (INR) according to the present consumer price index.

## 2.4 Materials and Methods

### 2.4.1 Study Area

#### 2.4.1.1 Greater Hyderabad Municipal Corporation

Hyderabad is the capital city and most populous city in the Indian state of Telangana. The Greater Hyderabad Municipal Corporation (GHMC) is an urban conglomeration comprising of two main cities, that is, Hyderabad and Secunderabad, along with its suburbs shown in Fig. 2.1. The study area is holding 9.7 million human habitants and spreads over an area of 550 km<sup>2</sup>, which is further divided into 6 zones and 30 circles for administration convenience. It extends between 17°20'N to 17°60'N latitude and 78°23'E to 78°68'E longitude and receives an average precipitation of 840mm (Agilan et al. 2015). The river Musi which originates in Vikrabad flows in the city that acts as natural carrier to drain the water. The GHMC experiences an arid climate with mean monthly temperature varying 22.6°C in January and 32.3°C in May (Warrier et al. 2011). The average elevation is 580m above mean sea level and is located in Deccan plateau.

The study area serves as an industrial hub for pharma and life sciences, food processing and service sector, since it is stressed with 27% of state's population living in 0.8% of state's area. It shares almost half (43.5%) of total gross state domestic product (GSDP) of Telangana. The economic growth attracted population inside and outside the state of Telangana that resulted in unregulated land use practices.

#### 2.4.1.2 Chennai Metropolitan Area

Chennai is one of the oldest municipal corporations in the world and serves as the capital of the Indian state of Tamil Nadu. The Chennai Metropolitan Area (CMA) comprises Greater Chennai Corporation, Avadi Corporation, Tambaram Corporation and its suburbs, which accounts for 12 million people spread over 1182 km<sup>2</sup> and

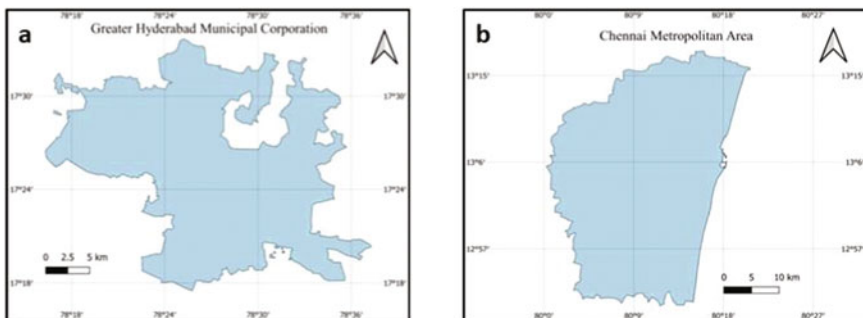
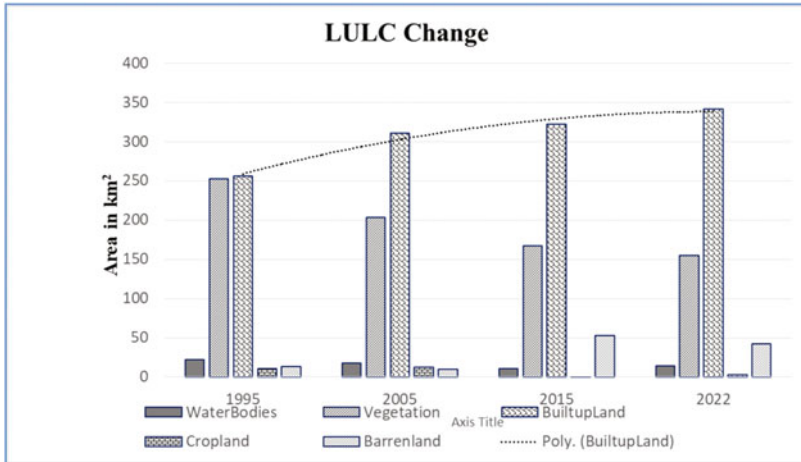


Fig. 2.1 Location of study area – (a) GHMC and (b) CMA



**Fig. 2.2** Trend in LULC variation for GHMC from 1995 to 2022

shown in Fig. 2.2. The study area experiences a tropical wet and dry climate and is highly humid because of its location. It receives rainfall on an average of about 1400 mm where 60% of it occurs between October and December, that is, due to northeast monsoon (Devi et al. 2019). Three rivers Cooum, Adayar and Kosasthailayar flow in the study area and drains into the Bay of Bengal. Buckingham Canal once served as a navigational channel runs parallel to the coast. Heavy industrialization and urbanization in post-independence period sound the need for ecosystem valuation.

#### 2.4.2 Data Source and LULC Classification

The estimation of ESVs depends on the accurate measurement of proportionate area that falls under each ecoregion, since an ecoregion offers unique ecosystem services. Remote sensing data products are reliable source for quantifying area under each ecoregion. For the study, geometrically and radiometrically calibrated Landsat data are obtained from the US Geological Survey (USGS) Earth Explorer that is for different time periods. The detail description of Landsat data used in the study is given in Table 2.1. The data for the month of January (with cloud cover less than 10%) are considered for the analysis for the years 1995, 2005, 2015 and 2022, in order to eliminate the seasonal variation and to maintain consistency in classification.

The data are classified into five LULC classes, that is, waterbodies, vegetation, builtup, cropland and barrenland, using a supervised machine learning algorithm, namely, support vector machine (SVM). The LULC classification using SVM has produced better accuracy (Sannigrahi et al. 2019) comparing with other techniques

**Table 2.1** Description of the record of Landsat data for different years used in the study

Year	Data	Sensor	Month of image acquisition	Spatial resolution (m)
1995	Landsat 5	TM	January 1995	30
2005	Landsat 5	TM	January 2005	30
2015	Landsat 8	OLI	January 2015	30
2022	Landsat 9	OLI	January 2022	30

like Artificial Neural Network, Decision Tree and Maximum Likelihood Classification. Google Earth Engine is used to classify the images, since it reduces the tedious task of data handling. The cloud-based setup helps us to derive and store the output without need for handling many temporary data.

The platform's code editor is used to obtain the Landsat data and filtered for minimal cloud cover. An average of 200 training point is considered for individual class, that is, waterbodies, cropland, vegetation, builtup and barrenland, and Support Vector Machine (SVM) classifier (libsvm) is used for the supervised classification. The classified data for the years of 1995, 2005, 2015 and 2022 are used to obtain the proportionate area under each class and are analysed for spatiotemporal variations in an individual classed over the time period of study. The year 1995 was taken as reference period to define the variation in LULC classes and estimated as follows:

$$\Delta LULC_i = \frac{LULC_{final} - LULC_{initial}}{LULC_{initial}} \times 100$$

where  $\Delta LULC_i$  is the change in an individual LULC observed during the time frame and  $LULC_{final}$  and  $LULC_{initial}$  is the particular LULC unit at the beginning and ending of the study. The average overall accuracy assessment of supervised classification for the study areas of CMA and GHMC is 73% and 55%, respectively. The accuracy can be enhanced by a more apparent distinction between cropland and barrenland, as non-cultivable areas are classified as barrenland. The flaws in the classification limit the study.

### 2.4.3 Estimation of Ecosystem Service Values

Ecosystem service value is estimated as the summation of product of the ecosystem coefficient (for LULC classes and ecosystem services) with proportionate area of LULC classes. We considered 17 ecosystem services offered by individual LULC classes and the value for ecosystem service coefficient obtained from Sannigrahi et al. (2019) are listed in Table 2.2. And the ESV can be mathematically computed with the following equation:

**Table 2.2** Ecosystem service value for different LULC classes in US\$/ha/year

Ecosystem services	Waterbodies	Vegetation	Cropland	Barrenland	Builtup
Gas regulation	0	0	0	10.06	0
Climate Regulation	13	6	215	0	26
Disturbance Regulation	81	0	0	0	0
Water regulation	166	0	0	15.1	1
Water supply	12	10	234	0	0
Erosion control	88	8	74	10.06	0
Soil formation	0	0	370	0	0
Nutrient cycling	51	0	0	0	0
Waste treatment	82	11	208	50.32	0
Pollination	0	5	12	0	0
Biological control	26	5	17	0	0
Habitat service	66	184	0	10.06	0
Food production	17	181	1269	0	0
Raw material	15	8	115	0	0
Genetic service	3	184	546	0	0
Recreation	60	4	43	0	161
Cultural service	54	25	0	5.03	0

$$ESV_i = \sum_{j=1}^{17} aV_{ck} \times A_j$$

where  $ESV_i$  is the ecosystem service value offered by an individual class and  $V_{ck}$  is the ecosystem service coefficient for individual ecosystem service in US\$/ ha/year:

$$ESV_{total} = \sum_{i=1}^5 aESV_i$$

$ESV_{total}$  in a year is the total ecosystem service value offered by all individual LULC classes from their services. The change in  $ESV$  ( $\Delta ESV_i$ ) is calculated as follows:

$$\Delta ESV_i = \frac{ESV_{final} - ESV_{initial}}{ESV_{initial}} \times 100$$



## 2.5 Results and Discussion

### 2.5.1 *Classification and Spatiotemporal Changes of LULC*

#### 2.5.1.1 GHMC

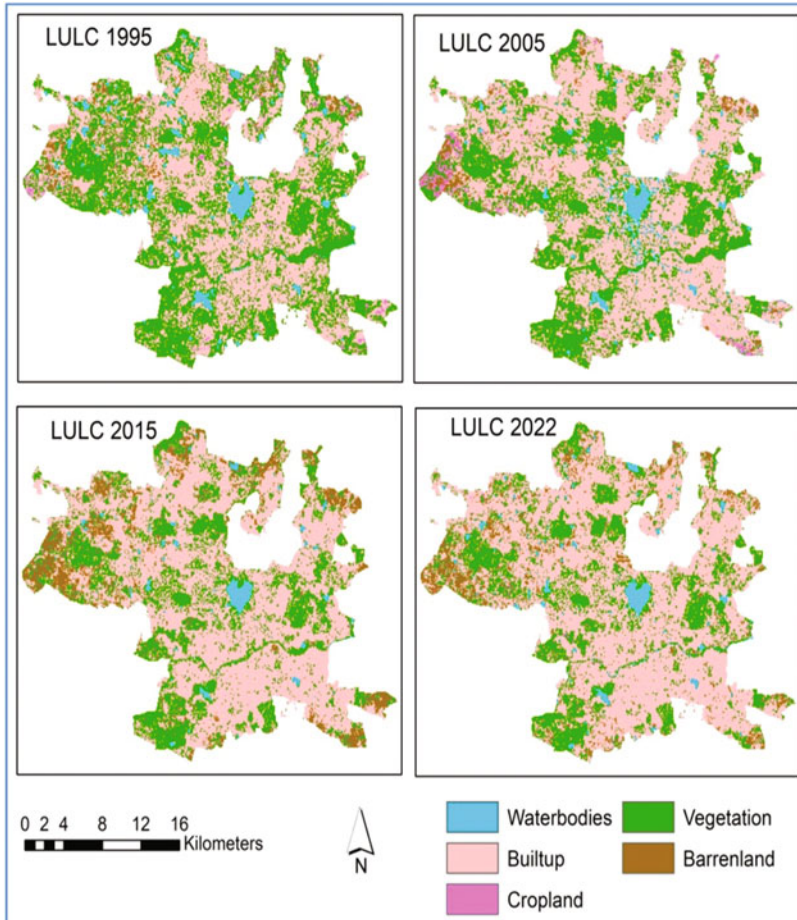
In the year 1995, the LULC class vegetation and builtup are found to be the predominant land cover category (46.5% and 46%) followed by waterbodies (4%), and then cropland and barrenland are the least ones. The dominance of builtup in LULC is found in 2005, and vegetation class is found to have considerable loss in proportion of area as shown in Fig. 2.2.

During the years 1995–2022, builtup area has increased 33% at the cost of vegetation and waterbodies changing the study area landscape with builtup as the dominant category.

The spatiotemporal changes in the study area are presented in Fig. 2.3. Even though the reduction in area of waterbody is observed, the rate of decrease in the area from 2015 to 2022 is very low compared to the rate of decrease from 2005 to 2015. The area under waterbodies, vegetation and cropland has shrunk to 36.05%, 38.69% and 75.13%, respectively, during the period of study between 1995 and 2022. Meanwhile the area under builtup and barrenland are found to increase 32.98% and 218.02% during the study. The decade of 2005–2015 has witnessed sharp transition in area under each LULC class, that is, the area under waterbodies, cropland and vegetation has been transformed into other LULC classes.

#### 2.5.1.2 CMA

The Chennai Metropolitan Area had builtup as the dominant land category occupying 32.48% of total area followed by cropland, vegetation, barrenland and then waterbodies (29.62%, 14.91%, 13% and 10.14%), respectively, in 1995. The areas under builtup and barrenland are found to increase during the study period of 1995–2022 amounted to 36.46% and 42%, respectively, as seen in Fig. 2.4. Vegetation, cropland and waterbodies are found to follow decreasing trends throughout the study period, and estimated percentage losses in the area compared with the reference year are 24.8%, 30% and 45.96%, respectively. The increasing area under builtup and barrenland could be attributed with the decrease in the area associated with the LULC class of vegetation, cropland and waterbodies (Fig. 2.5).



**Fig. 2.3** Spatiotemporal variation of LULC observed in GHMC (1995–2022)

## 2.5.2 *Ecosystem Service Values*

### 2.5.2.1 GHMC

Figure 2.6 depicts the ESV derived from each LULC in GHMC. Waterbodies provide 14 ecosystem services out of 17 considered for this study, and it contributes to 1.8 million US Dollars (USD) in the year 1995 (Costanza et al. 1997) and gradually reduced to 1.7 million USD in 2005, 1.8 million USD in 2015 and 1.14 million USD in 2022. Vegetation provides 12 ecosystem services and contributed 18.16 million USD in the year 1995. It is the highest contributed LULC class to ESV and then decreasing throughout the study period as 16.95 million USD in 2005,

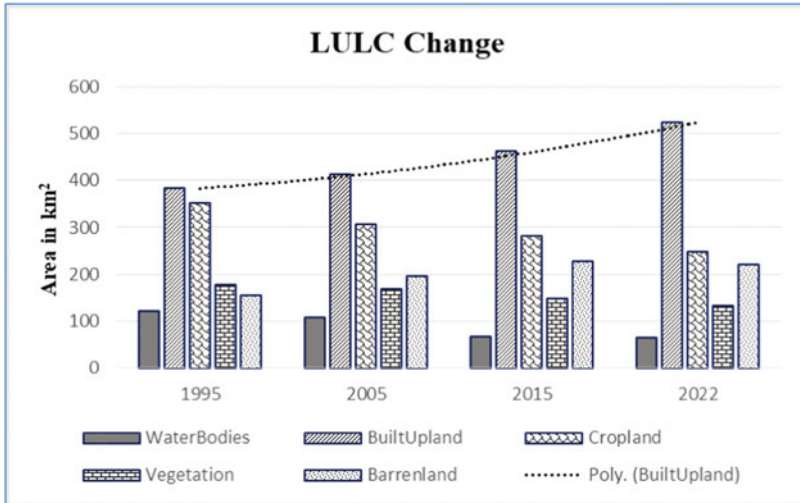
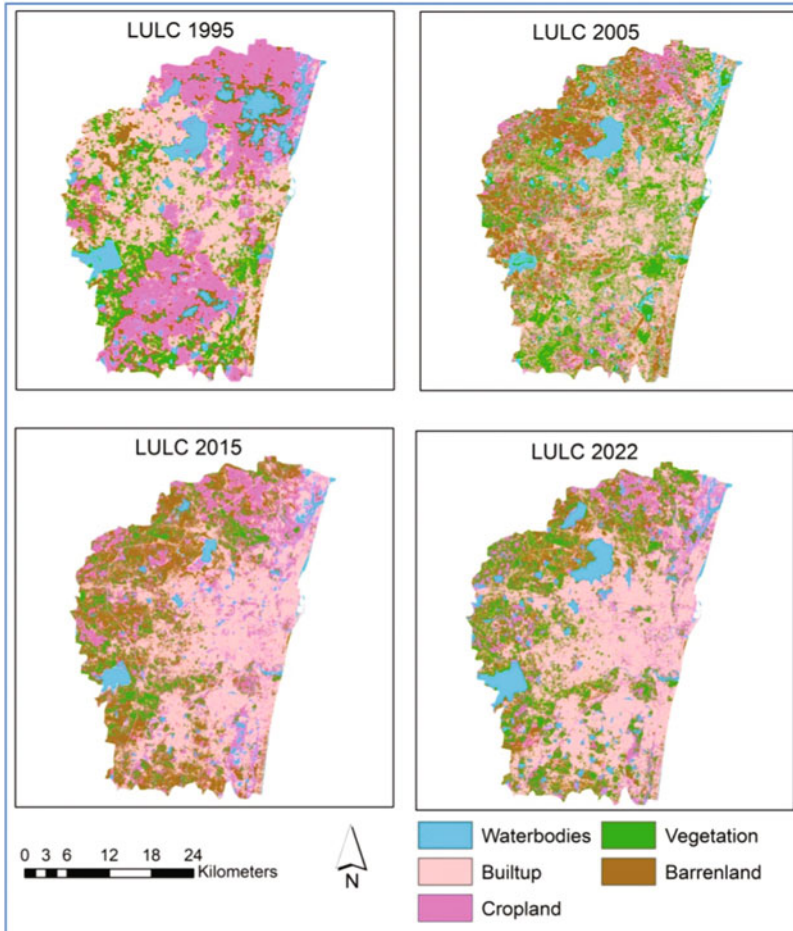


Fig. 2.4 Trend in LULC variation for CMA from 1995 to 2022

14.31 million USD in 2015 and 10.23 million USD in 2022 indicating the rate of decrease in ESV increasing as the time progressed.

Climate regulation, water regulation and recreation are the services provided by the builtup class. The valuation of these services is estimated around 4.5 million USD in 1995 and found to be a decreased till the end of the study period (4.9 million USD in 2005, 5.88 million USD in 2015 and 7.1 million USD in 2022). The rate of increase in ESV was found to be increased during later time period of study (2005–2015, 2015–2022). Though builtup is a dominant land use category, the net ecosystem services derived from it were less compared with another existing natural ecosystem. From this study, it is evident that there is a linkage between LULC and ecosystem service values. The reduction in the area of waterbodies (37.67%) has reflected in ESV, that is, the share in total ESV dropped from 6.45% in 1995 to 5.73% in 2022. Vegetation has drastically minimized in area by 43.6% where almost half of the area are converted into other eco-class. The contribution of vegetation to ESV dropped from 74% to 55% indicating the overall loss to the study area. The ecosystem services provided by vegetation have been following a decreasing trend throughout the period. The area under builtup found to be increased 33% during the period 1995–2022, the share to the total area calculated as 46.13% in 1995, 55.9% in 2005, 57.8% in 2015 and 61.8% in 2022.

The  $ESV_{total}$  is estimated 28.87 million USD in the year 1995 and 18.49 million USD in the year 2022 showing decreasing trend with an overall loss of 28.52% (10.38 million USD). The primary contribution of ESV is derived from vegetation followed by builtup, cropland and waterbodies, and this order continued even though there is net decrease in contribution from the individual classes except builtup. Production functions contribute higher share in ESV followed by information functions, habitat functions and regulation functions throughout the study as



**Fig. 2.5** Spatiotemporal variation of LULC observed in CMA (1995–2022)

shown in Fig. 2.7. The fivefold increase of area in barrenland observed between 2005 and 2015 has found to be decreased 20% during 2015–2022, along with the increase in builtup. This could be reasoned as the barrenland serves as an intermediate transition class towards the conversion of vegetation and cropland into builtup.

### 2.5.2.2 CMA

Cropland holds the highest share in contributing services to the ecosystem and is estimated to be 109 million USD in the year 1995, 94.9 million USD in 2005, 87.5 million USD in 2015 and 76.5 million USD in 2022 as shown in Fig. 2.8. Though cropland shares higher ESV among other eco-classes, there is constant decrease in

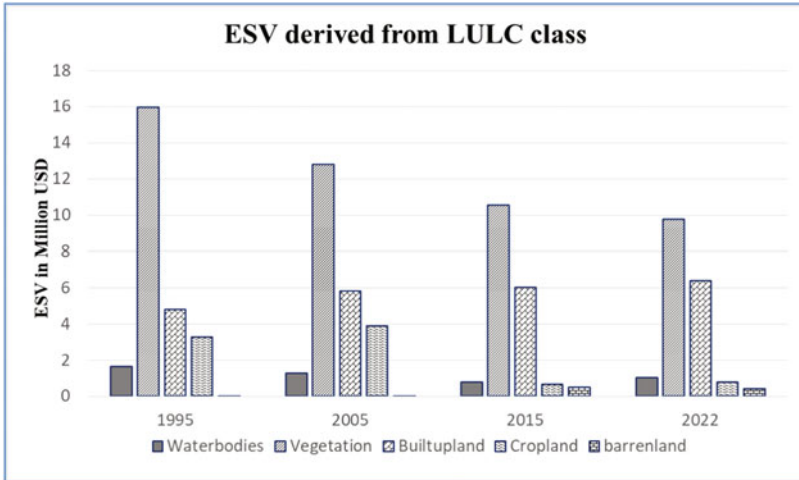


Fig. 2.6 The ESVs derived from LULC for GHMC

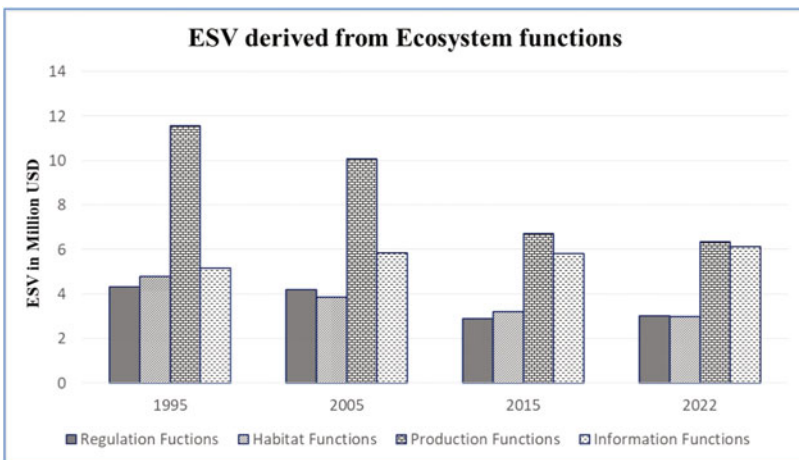
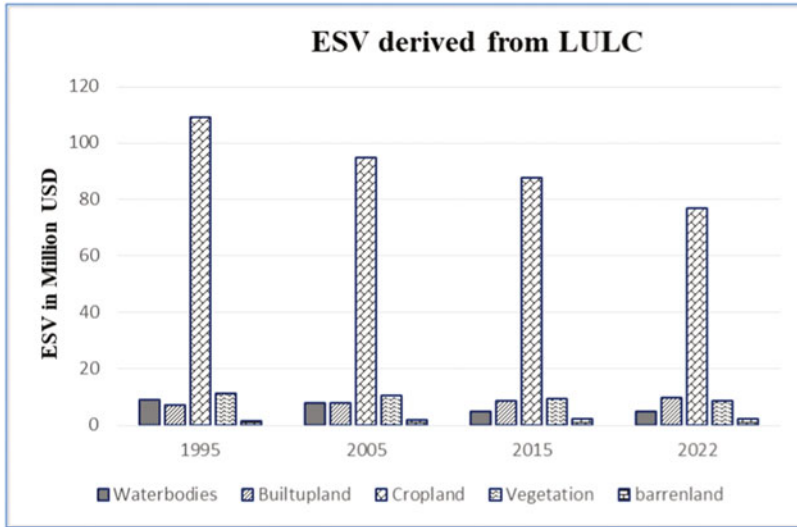


Fig. 2.7 The ESV derived from ecosystem functions for GHMC

ESV (30%) during the study period. The increase in ESV derived from the builtup does not significantly increase the total ESV as shown in Fig. 2.8.

This is a result of significant reduction in the area occupied by the cropland. Vegetation is the next highest contributor of ES in the CMA accounting 11.18 million USD, 10.56 million USD, 9.4 million USD and 8.4 million USD, and this eco-class too followed the decreasing trend in ESV as cropland during the study. Contradictorily, ESVs derived from builtup on the barrenland are found to be increasing throughout the study. This is reflected from decreasing trend in the area



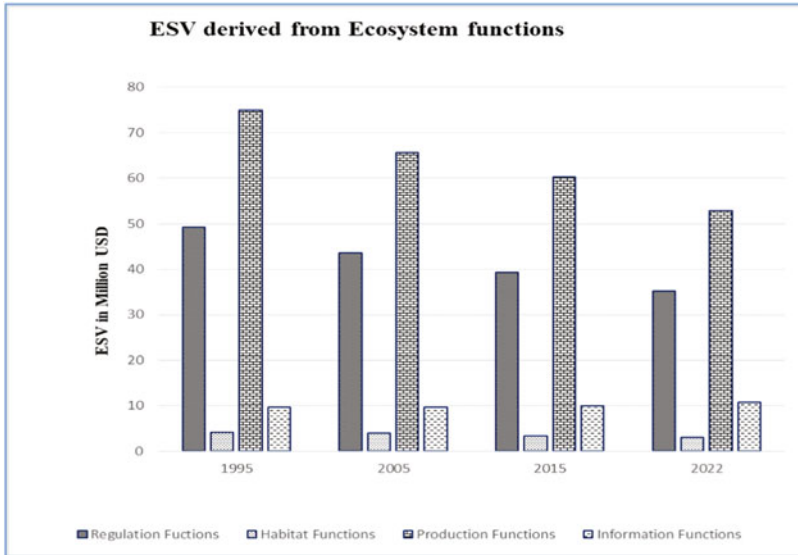
**Fig. 2.8** The ESV derived from LULC class for CMA

occupied by the waterbodies and increasing trend in area occupied by the buildup and barrenland during the study.

The ESV for the CMA is estimated as 138.03 million USD in the year 1995 and found decreased as 123 million USD in 2005, 112.91 million USD in 2015 and then 101 million USD in 2022. The loss incurred in ESV amounts during the study of 36.24 million USD (26.25%) is attributed to the increase in the buildup and barrenland whose ecosystem services contribution is minimum. Figure 2.9 clearly shows that the production function dominates other ecosystem functions in generating ESV but follows decreasing trend throughout the study. This trend is followed by regulation functions and habitat functions except information function, where ESV contribution is found with increasing trend throughout the study. Regulation functions that regulate and maintain the ecosystem through its services (climate regulation, water regulation and supply, disturbance regulation and waste Treatment) are found to have subsequent decrease in generation of ESVs between 1995 and 2022. This fact questions the resilience of the study area in climate change-induced extremes. The decrease in regulation function indicates loss in basic life support services derived from the ecosystem.

## 2.6 Conclusion

In this study, we have calculated the spatiotemporal ESVs of Greater Hyderabad Municipal Corporation (GHMC) and Chennai Metropolitan Area (CMA) from the different LULC data for the period 1995–2022. The monetary values for



**Fig. 2.9** The ESV derived from ecosystem functions for CMA

17 ecosystem services are calculated using ecosystem service coefficient values obtained from Sannigrahi et al. (2019). At instant builtup is the dominant land use category in the study, followed by vegetation and waterbodies, respectively. Due to the expansions in builtup, the ecosystem services such as climate regulation and recreation have increased during 1995–2022, whereas the decrease in ESV such as water regulation, water supply, erosion control, nutrient cycling, raw material and genetic services is observed due to shrinkage in the area under waterbodies and vegetation. It also describes the impact of human interference on ecosystem and natural capital. The study reveals that the area of our interest has undergone unregulated land use practices due to anthropogenic activities, since builtup is the only class found increased throughout the period of study. The study concludes that anthropogenic activities on LULC have severe impact on ecosystem functions and its derived ecosystem services. It is observed that years between 2005 and 2015 witnessed sharp transition in LULC and it could be reasoned with flowering economic activities. However, the reason has to be validated with further studies. The change detection analysis study on LULC would be able to quantify the transformation of one class into another and it limits the present study. Lastly, the study points that there is an overall loss in ESV derived from ecosystem services due to anthropogenic activities, 6 (clean water and sanitation, good health and well-being, sustainable cities and communities, climate action, life below water, life on land) out of 17 Sustainable Development Goals are more affected. The result of this study would be helpful in understanding the LULC dynamics and its associated changes in the ESV values to frame policies to attain ecosystem sustainability.

## References

- Agilan V, Umamahesh NV (2015). Detection and attribution of non-stationarity in intensity and frequency of daily and 4-h extreme rainfall of Hyderabad, India. *J Hydrol*, 530, 677–697. <https://doi.org/10.1016/j.jhydrol.2015.10.028>
- Chopra B, Khuman YSC, Dhyani S (2022) Advances in ecosystem services valuation studies in India: learnings from a systematic review. *Anthropocene Sci* 1(3):342–357. <https://doi.org/10.1007/s44177-022-00034-0>
- Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG (1997) The value of the world's ecosystem services and natural capital. *Nature* 387(6630):253–260. <https://doi.org/10.1038/387253a0>
- Costanza R, Pérez-Maqueo O, Martínez ML, Sutton P, Anderson SJ, Mulder K (2008) The value of coastal wetlands for hurricane protection. *Ambio*:241–248. <https://doi.org/10.1016/j.gloenvcha.2021.102328>
- Costanza R, Kubiszewski I, Ervin D, Bluffstone R, Boyd J, Brown D et al (2011) Valuing ecological systems and services. *F1000 biology reports* 3. <https://doi.org/10.3410/B3-14>
- Costanza R, De Groot R, Sutton P, Van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. *Glob Environ Chang* 26:152–158. <https://doi.org/10.1016/j.gloenvcha.2014.04.002>
- Das M, Das A (2019) Dynamics of urbanization and its impact on urban ecosystem services (UESs): a study of a medium size town of West Bengal, Eastern India. *J Urban Manag* 8(3): 420–434. <https://doi.org/10.1016/j.jum.2019.03.002>
- De Groot RS, Wilson MA, Boumans RM (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol Econ* 41(3):393–408. [https://doi.org/10.1016/S0921-8009\(02\)00089-7](https://doi.org/10.1016/S0921-8009(02)00089-7)
- De Groot RS, Alkemade R, Braat L, Hein L, Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol Complex* 7(3):260–272. <https://doi.org/10.1016/j.ecocom.2009.10.006>
- De Groot R, Brander L, Van Der Ploeg S, Costanza R, Bernard F, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S (2012) Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst Serv* 1(1):50–61. <https://doi.org/10.1016/j.ecoser.2012.07.005>
- Devi NN, Sridharan B, Kuiry SN (2019). Impact of urban sprawl on future flooding in Chennai city, India. *J Hydrol*, 574, 486–496. <https://doi.org/10.1016/j.jhydrol.2019.04.041>
- Kreuter UP, Harris HG, Matlock MD, Lacey RE (2001) Change in ecosystem service values in the San Antonio area, Texas. *Ecol Econ* 39(3):333–346. [https://doi.org/10.1016/S0921-8009\(01\)00250-6](https://doi.org/10.1016/S0921-8009(01)00250-6)
- Liu Y, Li J, Zhang H (2012) An ecosystem service valuation of land use change in Taiyuan City, China. *Ecol Model* 225:127–132. <https://doi.org/10.1016/j.ecolmodel.2011.11.017>
- Sannigrahi S, Rahmat S, Chakraborti S, Bhatt S, Jha S (2017) Changing dynamics of urban biophysical composition and its impact on urban heat Island intensity and thermal characteristics: the case of Hyderabad City, India. *Model Earth Syst Environ* 3:647–667. <https://doi.org/10.1016/j.jenvman.2019.04.095>
- Sannigrahi S, Chakraborti S, Joshi PK, Keesstra S, Sen S, Paul SK, Kreuter U, Sutton PC, Jha S, Dang KB (2019) Ecosystem service value assessment of a natural reserve region for strengthening protection and conservation. *J Environ Manag* 244:208–227. <https://doi.org/10.1016/j.jenvman.2019.04.095>
- Sannigrahi S, Zhang Q, Joshi PK, Sutton PC, Keesstra S, Roy PS, Pilla F, Basu B, Wang Y, Jha S, Paul SK (2020a) Examining effects of climate change and land use dynamic on biophysical and economic values of ecosystem services of a natural reserve region. *J Clean Prod* 257:120424. <https://doi.org/10.1016/j.jclepro.2020.120424>
- Sannigrahi S, Zhang Q, Pilla F, Joshi PK, Basu B, Keesstra S, Roy PS, Wang Y, Sutton PC, Chakraborti S, Paul SK (2020b) Responses of ecosystem services to natural and anthropogenic



- forcings: a spatial regression based assessment in the world's largest mangrove ecosystem. *Sci Total Environ* 715:137004. <https://doi.org/10.1016/j.scitotenv.2020.137004>
- Vikramani A (2006) India's economic growth history: fluctuations, trends, break points and phases. *Indian Econ Rev* 41:81–103. <https://www.jstor.org/stable/29793855>
- Warrier CU, Babu MP (2011) A comparative study on isotopic composition of precipitation in wet tropic and semi-arid stations across southern India. *J Earth Syst Sci* 120, 1085–1094. <https://doi.org/10.1007/s12040-011-0121-2>