Effect of urbanization on the dynamics of ecosystem services: An analysis for decision making in Kolkata urban agglomeration

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Abstract
Urbanization has profound influence on the changes of land use and land cover, which on the other hand exert significant impact on ecosystem services and their values, especially in the urban agglomerations. Kolkata urban agglomeration of India has been selected to determine the causes in changes of ecosystem services under present and projected land use land cover scenario. Land use land cover maps of 1990, 2000, 2010 and 2020 were prepared by support vector machine method, using LANDSAT satellite imageries and projected up-to 2040 using CA–Markov model. Built-up land was increased by 65.39% during 1990–2020 and will further increase to 76.88% by 2040. Built-up lands are mainly encroaching crop lands and wetlands. During the period of fifty years (1990–2040), the ecosystem service value will decrease from $38,486.49 to $28,060.79, with annual rate of decrement of 0.54%. During the same period, the spatial extent of very low ecosystem service value will be increased from 16.60 to 58.88%; whereas, the area coverage of very high ecosystem service value will be decreased from 2.69 to 2.35%. Water supply contributed highest ecosystem service value followed by disturbance regulation and nutrient cycling; whereas, lacking in soil formation, pollination and biological control services contributed lowest. The study will help in decision making process for sustainable management of natural resources and also provide useful guideline for the quality improvement in urban ecosystems.

Keywords CA–Markov model · Ecosystem service value (ESV) · Land use/land cover (LULC) · Scenario analysis for ESV · Urban expansion

Introduction

The structure and functions of ecosystem services were maintained by the interaction of living organisms with their physical environment and exchanging energy and materials between them (Chapin et al. 2012). The condition or quality of an ecosystem is measured with the aid of a set of ecological processes, which is related to both the system’s ecological condition and its capacity to support ecosystem services (ESs). ESs make valuable contribution not only for human wellbeing (Alcamo et al. 2003; de Groot et al. 2012; Das and Das 2019a, b; Daily 1997; Millenium Ecosystem Assessment 2005) but also for living organisms, therefore appropriate services of ecosystem components should be provided for them as well (Costanza and Daly 1992; Fisher et al. 2009; Costanza et al. 1997). Ecosystem Service Values (ESVs) are the values assigned to goods and services derived from ecological processes and can be used to assess the impact of anthropogenic activities on different ecosystems (MEA 2005; Adekola et al. 2015); to analyze environmental-human development interactions, and to enhance sustainable management of natural resource (Braat and de Groot 2012). The evaluation and assessment of ESs has grown in importance as it can help cost–benefit analyses and decision making by incorporating both negative and positive effects of human development activities, such as Land Use and Land Cover (LULC) change on diverse ecosystems (Sannigrahi et al. 2020; Wang et al. 2018, 2019).
Expansion of urban area is one of the driving forces responsible for massive changes of ecological condition (Bolund and Hunhammar 1999; Chen and Chen 2007; Li et al. 2012; Aronson et al. 2014) and loss of natural capitals (He et al. 2016). Population explosion and related infrastructure development are very common phenomena in urban area, which changes the LULC pattern (Das et al. 2020; Gao et al. 2017). As a result, natural ecosystems are slowly transforming to human-nature ecosystems, and destroying the ecosystem structure and functions (Shao et al. 2017; Wang et al. 2017). The environmental sustainability and regenerating capacity are under great threats due to loss of water bodies and vegetation cover within urban space (Daniel et al. 2012; Keshtkar et al. 2017). It may increase temperature in urban areas and causes urban heat island effect (Manoli et al. 2019), urban flood effect (Gupta 2002) and declines or shifts ESs (Richards et al. 2020; Das and Das 2019a, b; Bohnet and Pert 2010).

Investigations of ESVs are very common and popular among the researchers around the world (Liu et al. 2020; Li et al. 2012; Maes et al. 2013; Odgaard et al. 2017; Song 2018). Many researchers (Danz et al. 2007; Robards et al. 2011) have emphasized that how human activities lead to changes of ESs. Harrison et al. (2018) overviewed the ecosystem services methods like Ecosystem Service Modelling (ESM), Integrated Assessment Modelling (IAM), Simple GIS Mapping (SGM), Multi-criteria Decision Analysis (MCDA) etc. The ESM method assesses the supply of multiple ecosystem services based on specialised GIS software environment like QUICKScan, ESTIMAP and InVEST model (He et al. 2016). SGM is a basic method for mapping the valuation of different ESs types based on GIS. MCDA is a collective functional approach to accumulate multiple criteria that helps for decision making (Munda 2004). The IAM method couples together models representing different sectors or ecosystem components to simulate land use change and/or the delivery of ecosystem services, which simulates past, present and future impacts of human activities on ecosystem services (Schulp et al. 2012). The present study adopted IAM method to represent the impact of urbanization on ESV in the past, present and future scenario.

The urbanization process continuously converts the natural capitals; thus, it is very harmful for ecosystem functions (Derkzen et al. 2015; Wang et al. 2019). Currently, a large number of research articles have analysed the impacts of urbanization on ecosystem services from their own perspective (Bera et al. 2021). Das and Das (2019a, b) observed that rapid urbanization changes the urban ESs. Richards et al. (2020) established that rapid urbanization causes to shift of ESs. Thus, assessment as well as estimation of the loss of ESs due to continuous urban expansion contributes significantly for future planning and sustainable urban development at regional scales.

Kolkata Urban Agglomeration (KUA), one of the many mega urban agglomerations of the world, is experiencing a rapid change in LULC because of its urban expansion. It leads to rapid decline of ecological environmental quality of the region and thus deteriorated the ecosystem services (Mukherjee 2012). Works were evidenced on the spatial pattern of urbanization (Sahana et al. 2018), spatial nature of ecological environmental quality (Maity et al. 2022), landscape fragmentation nature (Das et al. 2021) but, effects of urbanization on ESs were not assessed. Although, monitoring of spatial and temporal change of ESVs in KUA will help the planners and decision makers to adopt appropriate strategies for betterment of the standard of living of the people living there. The future change of ESVs will have direct repercussion with the LULC changes and indirectly affect the life of common people. Keeping these points in mind, the objectives of this study were (1) to map the spatial and temporal patterns of LULC change in KUA from 1990 to 2020 and their projection up to 2040; (2) to assess and predict the dynamics of ESV from 1990 to 2040 and highlights the ecosystem services which are most vulnerable; and (3) to provide road map for promoting economic development through balanced management of ESV.

Materials and methods

Study area

The Kolkata city is located by the side of east and west bank of River Hooghly (Ganges Delta). The business, commercial, and financial activities in eastern and northeastern India are mainly controlled by the city Kolkata. But, the word ‘city’, in relation to Kolkata, is not an officially recognised term; however, it is popular and used when referred to describe Kolkata Urban Agglomeration (KUA). The KUA includes both rural and urban areas of approximately 1886.67 km², extends between 22°0′19″ N to 23°0′01″ N and 88°0′04″ E to 88°0′33″ E (Fig. 1). The KUA has five local Governments; however, the overall management, development and plan formulation of the area is maintained by Kolkata Metropolitan Development Authority (KMDA). It is also the third most populous city in India and 8th largest urban agglomeration in the world, with total population of approximately 14.11 million (Census of India, 2011). The population density has been increased by nearly 90.24% from 1901 to 2011. The KUA has been formed with 3 municipal corporations (Howrah, Kolkata and Chandan Nagar), 38 municipalities, 77 non-municipal urban towns, 16 outgrowths and 445 rural villages. The region is experiencing rapid LULC changes and facing population pressure on natural resources, socio-economic challenges and deteriorating ecosystem services (Ehrlich and Ehrlich 1981; Mukherjee 2012).
LULC classification and change detection

Historical LULC data were used to map the dynamics of LULC in KUA. The LULC data includes eight satellite images (Landsat 5 + TM, Landsat 7 + ETM, Landsat 8 + OLI) (path-row 138–44 & 138–45) for the years 1990, 2000, 2010 and 2020, which were downloaded from the website https://earthexplorer.usgs.gov. The detail description of the satellite images used in this study is given in Table 1. We have classified the LULC with the help of support vector machine (SVM) tool. The radial basis function kernel-based learning model, which is fixed in ENVI 5.3 software, was used for SVM classification to tackle the issues of binary classification (Wijaya et al. 2008). It utilizes hyper planes that augment the edges between the data points, which is called support vector (Vapnik 1998). A proper kernel function was provided in SVM arrangement to make precise hyperplanes, which lessens the error (Wijaya et al. 2008).

The SVM algorithm is depending on four parameters—the kernel width gamma (γ), the penalty parameter (C), the quantity of pyramids levels to utilize, and threshold value of the classification probability. The classification threshold probability is the most important component among these (Keshtkar et al. 2017). To sort-list the pixels into a single class, zero value has been allotted as the threshold. From that point onward, for the pyramid factor, once more, a value

Fig. 1 Location of Kolkata Urban Agglomeration (KUA), India
of zero has been allocated, which measure the picture at its full resolution. The reverse of the quantity of bands has been set automatically for the value of gamma. The following formula can express the radial basis kernel technique based SVM algorithm.

$$K(x_i, x_j) = e^{-\gamma(x_i-x_j)^2}, \gamma > 0$$

(1)

where $x_i$ and $x_j$ denotes vector features in the input space, and $\gamma$ is the width of the kernel function.

In the present study, supervised image classification and visual interpretation were combined for the preparation of LULC map where the classification scheme of Roy et al. (2015) was used. The prepared seventeen LULC classes were reclassified into six categories: river, vegetation, wetland, cropland, built-up land and bare land. The accuracy assessment is an essential part of the LULC change mapping, because it validates LULC map with ground (Rwanga and Ndambuki 2017). For this purpose, 140 training points of each LULC types (total 840 points) were obtained from field survey to validate the LULC types (Elkhrachy 2015).

The value of kappa coefficient determined the overall classification accuracy.

Using the LULC maps for the years 1990, 2000, 2010, 2020, 2030 and 2040, the spatio-temporal dynamics and change of LULC were assessed for five decadal periods i.e. 1990–2000, 2000–2010, 2010–2020, 2020–2030 and 2030–2040 with the help of following equation:

$$C_{LULC} = \frac{LULC_f - LULC_i}{LULC_i} \times 100$$

(2)

where, $C_{LULC}$ is the decadal change of a particular LULC in per cent, $LULC_i$ is the LULC at the end of the decade and $LULC_i$ is the LULC at the start of the decade.

### LULC prediction using CA–Markov model

LULC maps for the years 1990, 2000, 2010 and 2020 were prepared with the help of GIS and remote sensing techniques. Then, the LULC for the years 2030 and 2040 was predicted using CA–Markov model. The Markov model is a
very popular technique used to calculate transitional probability of LULC types within observed time period (Guan et al. 2011; Lou et al. 2014; Shaﬁzadeh and Helbich 2013). The transitional probability means the probability of change of land cover type (pixels) in future. It expresses as transitional probability matrix if time \( t_0 \) changes to another land cover type in the time \( t_1 \). Thus, the technique is helpful to predict LULC scenario but cannot give spatial information. The combination of Markov model and Cellular Automata (CA–Markov) simulate LULC scenario and gives spatial information with projected map (Sang et al. 2011). The LULC change predicting model was constructed using IDRISI software to explore the spatial patterns of projected LULC scenario. We have used LULC 1990 map as a base map, further used to determine LULC probability and project LULC patterns. This involves three steps. (1) Computation of transitional probability matrix in Markov model based on LULC map 1990 and 2020. (2) Computation of CA filter in CA–Markov model, where we have used 5 \( \times \) 5 pixels contiguity as filter standard factor and kept the number of cellular automata interactions as 10. The CA–Markov model applies a contiguity kernel, help to grow out a LULC map based on CA function. It measured the state change of the cells by considering the distance between neighbour and cell. (3) Finally, LULC change prediction map of 2030 has been projected and the same procedure was applied to project the LULC change prediction map of 2040.

**Assessment of ecosystem service value**

**Estimation and prediction of ESVs**

LULC change affects the structure and function of ecosystem, which play a key role in maintaining ecosystem services (Song and Deng 2015; Zhang and Gao 2016). The principles and methods about the value assessment of ESs was analysed by Costanza et al. (1997). They computed global coefficient value for 17 ecosystem services of different LULC types. Recently, Costanza (2014) has modified these values and for Asian countries Xie et al. (2008) have given coefficient values to calculate ESV. In the present study we adopted these coefficient values for six LULC types (river, vegetation, wetland, cropland, built up land and bare land) and modified for our need. For the purpose of estimation of ESV, study area has been sub-divided into 1 km \( \times \) 1 km grids and then the ESVs of different LULC types within each grid were measured. The detail description of adopted coefficient value is given in Table 2. The details methodological flow-chart is given in Fig. 2.

We estimated the ESV from the year 1990 to 2020 based on the LULC map and predicted ESV for 2030 and 2040 based on the projected LULC map. The following equations were applied to calculate ESV for LULC types, LULC functions and total ESV, which were used in the adopted model for the study area.

\[
ESV_f = \sum_j (A_k \times VC_{kf})
\]

\[
ESV_k = \sum_k (A_k \times VC_{kf})
\]

\[
ESV_t = \sum_k \sum_f (A_k \times VC_{kf})
\]

where \( ESV_f \), \( ESV_k \) and \( ESV_t \), represents ecosystem service value of LULC function \( f \), ecosystem service value of LULC type \( k \), and total ecosystem service value, respectively; \( A_k \) represents the area (km\(^2\)) for land use type \( k \); \( VC_{kf} \) is the coefficient value (US $/km^2/year) for land use type \( k \) and function \( f \).

**Change rate of ESV**

We have analysed grid-wise change rate of ESV to know the spatial locations where ESV has declined rapidly. It was calculated using the following equation:

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Where, CESV means change rate of ESV; ESV<sub>c</sub> and ESV<sub>p</sub> represents ESV for current year and previous year and T represent time period.

Result

LULC change analysis during 1990 – 2040

LULC maps were classified based on SVM method, whereas CA–Markov model was used for the prediction of futurastic LULC maps. Six LULC types for the years 1990, 2000, 2010, 2020, 2030 and 2040 were identified as (1) river, (2) vegetation, (3) wetland, (4) cropland, (5) built-up land, and (6) bare land. The spatial distributions of all the LULC types for six different years are presented in Fig. 3. The study revealed that, during 1990, water body and wetlands covered nearly 10.48% area of KUA and reduced to 8.29% in 2020. The spatial extent of all the LULC types was reduced during 1990–2040, except for built-up land (Table 3). Figure 3 showed that expansion of built-up land mainly engulfed croplands, wetlands and vegetation lands. The LULC prediction using CA–Markov model states that water body will be reduced by 8.19% in between 2020–2040, whereas, built-up land will be increased by 6.95%. The present study also estimated decadal rate of change of different LULC types. River, vegetation, wetlands, cropland and bare land changed negatively, whereas the built-up land changed positively (Table 4). Highest average negative rate of change was observed for croplands. The cropland was decreased by -14.71%, -11.54%, -13.24%, -4.81% and -0.50%, respectively during the periods 1990 – 2000, 2000 – 2010, 2010 – 2020, 2020 – 2030 and 2030 – 2040. During the same period, the rate of change of built-up land was always positive to the tune of 25.51%, 17.88%, 11.79%, 5.34% and 1.52%, respectively. The wetlands were also significantly changed; -5.26%, -13.67%, -9.04%, -6.68% and -1.87% during the periods 1990 – 2000, 2000 – 2010, 2010 – 2020, 2020 – 2030 and 2030 – 2040, respectively (Table 4). This information indicates that increased built-up land is closely linked to conversion of wetlands and croplands in the study area. The negative rate of change for river, vegetation and bare land was low between the observed periods.
Urban expansion

KUA is the third most populated city in India which has experienced rapid urbanization from 1990 to 2020. The built-up land was expanded from 450.86 km² during 1990 to 745.69 km² during 2020 (Fig. 4) with a growth of 65.39% (Table 5). The population was increased by 75.29% from 1991 to 2021. The trend of change of built-up land is directly coinciding with the change of population in KUA. During the period 2001–2021 the growth rate of population as well as built-up land remained lower than other decades. Figure 4 showed the spatial expansion of built-up land from 1990 to 2040. The expansion of built-up land was high in south Kolkata (Sonarpur and Baruipur Municipality, Bhangar-I and Bhangar-II) and mainly expanded after 2000.

Table 3 Summary statistics of classified and simulated LULC dynamics in KMA from 1990 – 2040

| LULC types | Classified area | | | | Simulated area | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | | | |
| | km² | % | km² | % | km² | % | km² | % | km² | % | km² | % |
| River | 60.01 | 3.35 | 56.49 | 3.15 | 55.73 | 3.11 | 53.59 | 2.99 | 51.26 | 2.86 | 49.41 | 2.76 |
| Vegetation | 395.21 | 22.06 | 378.41 | 21.12 | 354.49 | 19.79 | 338.52 | 18.90 | 331.58 | 18.51 | 326.05 | 18.20 |
| Wetland | 127.71 | 7.13 | 120.89 | 6.75 | 104.36 | 5.83 | 94.93 | 5.30 | 88.59 | 4.95 | 86.94 | 4.85 |
| Cropland | 505.73 | 28.23 | 431.33 | 24.08 | 381.56 | 21.30 | 331.05 | 18.48 | 315.11 | 17.59 | 313.54 | 17.50 |
| Built-up | 450.86 | 25.17 | 565.87 | 31.59 | 667.03 | 37.23 | 745.69 | 41.63 | 785.53 | 43.85 | 797.49 | 44.52 |
| Bare land | 251.89 | 14.06 | 238.42 | 13.31 | 228.24 | 12.74 | 227.63 | 12.71 | 219.34 | 12.24 | 217.98 | 12.17 |
Assessment of ESV from 1990 to 2040

The assessment of ESV has three dimensions—(1) Examining spatio-temporal variation of ESV in the present landscape scenario from 1990 – 2040; (2) Tracing out ecosystem services function and contribution of regulating, provisional, supporting and cultural ESs from 1990 – 2040; and (3) calculating LULC wise contribution of ESV in the study landscape scenario during the study period.

### Table 4 Decadal change of LULC in KMA starting from 1990 to 2040

| LULC types | 1990—2000 | 2000—2010 | 2010—2020 | 2020—2030 | 2030—2040 |
|------------|-----------|-----------|-----------|-----------|-----------|
| River      | -3.52     | -0.76     | -2.14     | -2.33     | -1.85     |
|            | -5.87     | -1.35     | -3.83     | -4.36     | -3.61     |
| Vegetation | -16.80    | -23.92    | -15.97    | -6.94     | -2.07     |
|            | -4.25     | -6.22     | -4.58     | -5.53     | -1.64     |
| Wetlands   | -6.82     | -16.53    | -9.43     | -6.34     | -1.65     |
|            | -5.26     | -13.67    | -9.04     | -6.68     | -1.87     |
| Cropland   | -74.40    | -49.77    | -50.51    | -15.94    | -1.57     |
|            | -14.71    | -11.54    | -13.24    | -4.81     | -0.50     |
| Built up   | 115.01    | 101.16    | 78.66     | 39.84     | 11.96     |
|            | 25.51     | 17.88     | 11.79     | 5.34      | 1.52      |
| Bare land  | -13.47    | -10.18    | -0.61     | -8.29     | -1.36     |
|            | -5.35     | -4.27     | -0.27     | -3.64     | -0.62     |

### Table 5 Urban expansion along with population growth in KMA from 1990 to 2020

| Years     | Growth of built-up land (%) | Years     | Growth of population (%) |
|-----------|----------------------------|-----------|--------------------------|
| 1990—2000 | 25.51                      | 1991—2001 | 55.41                    |
| 2000—2010 | 17.88                      | 2001—2011 | 6.81                     |
| 2010—2020 | 11.79                      | 2011—2021 | 5.60                     |
| 1990—2020 | 65.39                      | 1991—2021 | 75.29                    |

### Fig. 4 Spatial extent of urban expansion in KUA from 1990 to 2040
Fig. 5  Spatial distribution of ranges ESV within KUA during various time periods a 1990, b 2020, c 2030, and d 2040
Spatio–temporal assessment of ESV

Figure 5 showed the spatio-temporal distribution of ESVs within KUA for the period of fifty years (1990–2040). Grid wise analysis of ESV was done and it was classified into 5 groups—very low (< $453.80), low ($453.81-$619.60), moderate ($619.61-$851.60), high ($851.61-$1229.60) and very high (> $1229.61). Higher orders of ESV sites were mainly concentrated at the eastern part of KUA where wetlands are situated. It was observed that 16.60% of the grids were under very low ESV group during 1990, which has been increased to 41.47% during 2020 and will be increased to 58.88% during 2040; whereas 2.69% of the grids belonged to very high ESV during 1990, has been decreased to 2.54% during 2020 and will be decreased to 2.35% during 2040 (Table 6). The area of higher order ESV ($619.61-$1229.60) will decrease from 41.26% to 16.18% during 1990 – 2040. Rapid increase of ESV of lower order (< $453.80) has link with rapid increase of built-up area in KUA.

Ecosystem service functions and their contribution

The study determined the contribution of ten ecosystem service functions in the present landscape and also analysed their change rate from 1990 – 2040 (Table 7). It was found that cultural and recreation services contributed highest ESV followed by soil formation and waste treatment in every respective year; whereas water regulation and gas regulation services contributed lowest ESV. The rate of change of contribution for all the ESVs has decreased over time except biodiversity maintenance, although the absolute value of each and every ESs showed a decreasing trend. Moreover, supporting services contributed highest ESV and provisional services contributed lowest ESV in every decadal year (Table 8). More interestingly the change rate of food production, recreation and cultural value of ESs remain high in the 50 years study period.

LULC contribution to ESV

According to our observation, the vegetation and wetlands together had contributed nearly 62.2% of the total ESV in 1990, but will be decreased to 50.3% in the year 2040. The contribution was $4036.71 and $3066.93 in 1990 but will be decreased to $3331.79 and $2089.59 in 2040 (Table 9). The sub-urbanization process caused to transformation of both wetlands and vegetation to built-up land and make significant impact of such degradation on ESV. The contribution of cropland, built-up land and river was 19.28, 12.49 and 5.14%, respectively for the year 1990 and the contribution of built-up land will be 25.50% in the year 2040. In the present landscape, contribution from bare land was not significant. Table 9 shows that contribution of ESV by each and every LULC has been decreased in between 1990 – 2040 except for built-up land, which means natural ecosystem characteristics are modified to human based ecosystem.

Change rate of ESV

We have prepared ESV change rate (%) map during the period of 1990 – 2000, 2000 – 2010, 2010 – 2020, 2020 – 2030 and 2030 – 2040 (Fig. 6). The change rate of ESV was high in the sub-urban areas in between 1990 – 2000 and it was more or less stable up to 2010. After that period, significantly high ESV change rate was observed in the urban core areas (during 2010 – 2020) and will be continuously spreading towards its peripheral region in between 2020 – 2040. LULC change, especially transformation of natural ecosystem to urban ecosystem is the main reason for such changes.

Model validation

Firstly, we have validated LULC maps and after that we have validated actual and predicated ESV. The present LULC map of 2020 has been validated with training samples collected from field observation. In that case, we have collected 140 sample data for each LULC type, where kappa coefficient value was more than 86%. Previous LULC maps of 1990, 2000 and 2010 were validated based on Google Earth training data and earlier literature study and found fit for presentation. Secondly, we have prepared predicted LULC map for the year of 2020 using CA–Markov model and also predicted ESV for that year. Actual ESV for the

**Table 6** Levels of ESV and their spatial extent in KUA for various time periods

| ESV Category | ESV score | 1990 | 1990 | 2020 | 2030 | 2040 |
|--------------|-----------|------|------|------|------|------|
|              | km² | %    | km² | %    | km² | %    | km² | %    | km² | %    | km² | %    |
| Very low     | $453.80 and below | 297.31 | 16.60 | 742.90 | 41.47 | 897.39 | 50.09 | 1054.73 | 58.88 |
| Low          | $453.81—$619.60 | 706.71 | 39.45 | 567.92 | 31.70 | 522.07 | 29.14 | 404.68 | 22.59 |
| Moderate     | $619.61—$851.60 | 652.29 | 36.41 | 358.46 | 20.01 | 265.21 | 14.80 | 226.48 | 12.64 |
| High         | $851.61—$1229.60 | 86.96 | 4.85 | 76.69 | 4.28 | 63.20 | 3.53 | 63.44 | 3.54 |
| Very high    | $1229.61 and above | 48.19 | 2.69 | 45.50 | 2.54 | 43.53 | 2.43 | 42.10 | 2.35 |

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(continued)
year 2020 and predicted ESV have been validated by plotting with 1:1 line and calculating $R^2$, Nash Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970), RMSE, MAE and Index of Agreement (AI) values (Fig. 7). The validation result indicated that there was good agreement between observed and predicted ESV with $R^2$, NSE and AI values was 0.95, 0.952 and 0.988, respectively. The error components were also very low as the value of RMSE and MAE were 5.346 and 4.361, respectively.

Discussions

Effect of natural and anthropogenic activity on LULC change

Precipitation and temperature are the very important factors that influence urban ecology. In KUA, the precipitation has been increasing and temperature has been decreasing over the past thirty years (Fig. 8). Therefore, traditionally this area is conducive for crop and tree growth. Enough rainfall is also having potential to facilitate for spreading and maintaining of water bodies. With these positive environmental factors there is one aspect in rainfall which mainly determines its storage and its influence on vegetation, which is the rainfall distribution. The rainfall distribution in KUA is highly skewed. More than 80% of annual rainfall occurs during four monsoon months (June–September) (Ramchandra and Aithal 2014). During this time, the runoff and stream flow increases tremendously, keeping very less chance for water infiltration and storage in the water bodies. Flat topography also hinders in storing the excess water that is flowing over land. Water scarcity during winter and summer season reduces the green patches within KUA. Apart from the climatic factors, anthropogenic factors play very important role in changing the LULC in KUA. KUA is one of the biggest cities in south-east Asia, where business development has been increased tremendously. The built-up land was increased many folds within a span of thirty years and the growth rate of built-up land was 65.39% during the period 1990 to 2020. During the same period the population was increased by over 75%.

The anthropogenic activities which have governed the ecosystem services are common in various megacities in south-east Asia. Kumar (2009) has studied the anthropogenic pressure on urban green spaces and ecosystems of Delhi state of India. That study mainly focussed on biodiversity change due to change of urbanization. The shrinkage of wetlands in Kolkata was investigated by Bhattacharya et al. (2012) and concluded about the importance of construction of wastewater treatment plants. In Bangalore city of India, Jaganmohan et al. (2012) emphasized about the importance of domestic gardens and apartment gardens to

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**Table 7** ESV function and change rate of ten ecosystem services during 1990–2040

| Ecosystem service type | 1990 (USD/km²/year) | 2000 | 2010 | 2020 | 2030 | 2040 | 1990–2000 | 2000–2010 | 2010–2020 | 2020–2030 | 2030–2040 | 1990–2040 |
|-----------------------|---------------------|------|------|------|------|------|-----------|-----------|-----------|-----------|-----------|-----------|
| Gas regulation        | 51.49               | 48.19| 47.79| 47.33| 46.93| -4.6  | -2.9      | -1.4      | -0.8      | 0.1       | -7.1      |
| Climate regulation    | 100.99              | 94.13| 89.00| 87.70| 84.90| -3.6  | -3.1      | -3.3      | -3.3      | -3.3      | -11.2     |
| Water regulation      | 34.14               | 31.32| 29.77| 29.77| 29.77| -0.2  | -0.2      | -0.1      | -0.9      | -0.9      | -0.6      |
| Soil formation        | 254.77              | 223.24| 217.55| 214.91| 211.34| -0.9  | -0.9      | -0.9      | -0.9      | -0.9      | -0.6      |
| Waste treatment       | 144.77              | 141.26| 138.54| 135.30| 132.62| -0.9  | -0.8      | -0.8      | -0.8      | -0.8      | -0.8      |
| Food production       | 86.31               | 79.83| 71.86| 65.95| 63.07| -6.6  | -6.6      | -6.6      | -6.6      | -6.6      | -6.6      |
| Raw materials provision| 87.00               | 83.16| 77.68| 73.83| 72.10| -4.4  | -4.4      | -4.4      | -4.4      | -4.4      | -4.4      |
| Recreation and cultural and aesthetics | 297.74 | 260.72| 235.87| 217.02| 214.26| -8.6  | -8.6      | -8.6      | -8.6      | -8.6      | -8.6      |
conserve biodiversity in urban ecosystem. The conservation of biodiversity has positive impact on ecosystem services. Therefore, integrated ecosystem services valuation and the greater effect of human on ESV cannot be ignored in fragile urban areas like Kathmandu in Nepal (Peh et al. 2016). The impact of anthropogenic activity on the changing pattern of ecosystem services of urban cities of Myanmar has been studied by Wang et al. (2018). Recently Zinia and McShane (2021) assessed and mapped the ecosystem services of Dhaka city of Bangladesh where they considered that climate and anthropogenic activities play the most dominant role for changing the ESVs. The expansion of urban area causes to degradation of natural ecosystem and changes of ecosystem services. This phenomenon linked with the process of ecosystem degradation in KUA.

**LULC change versus ESV change**

The changes in LULC scenario are the primary reason for the loss of ESV or the shifts of the type of ESs from one to another (Zhang and Gao 2020; Das and Das 2019b; Lang and Song 2019). In the KUA, the patterns of LULC change have been very dynamic during the year 1990 to 2020. In the first phase of 1990–2000, the massive growth of built-up area has been noticed, which has mainly reduced agricultural land. In the second phase of 2000 – 2010, high growth of built-up area has been continued but with quite low pace as compare to the first phase. The loss of wetlands has very high in this phase, which mainly transformed to the built-up land. Su et al. (2014) and Sahana et al. (2018) studied on urban spatial pattern and landscape change scenario. They noticed that urban secondary and primary core area were rapidly increased. The expansion of sub-urban fringe and scatter settlement areas also significantly noticed. Our analysis experienced that spatial process of urban expansion caused to shift of ESV in both urban core and sub-urban fringe areas. Many stakeholders are also affected both positively and negatively by the change of ESV. Natural habitat and wellbeing of other living organisms hampered due such ESV change.

Das and Das (2019b) classified the dimensions of urbanization into four categories—population urbanization, economic urbanization, lifestyle urbanization and landscape urbanization. Growth of population is the main indicator under population urbanization, which is the main feature of the development of a modern city and can changes natural resource consumption. Economic urbanization means a group of economic activities accommodated within cities and the distribution of this growth across cities of different sizes. Rich, material wellbeing, enrichment of civilization, education, improvement in living standards, etc. are the aspects of lifestyle urbanization. This type of urbanization cannot be spatially describable. But landscape urbanization means LULC changes and expansion of built-up land, which has links to population growth and leads to loss of natural landscape. Because of this reason, the present study considered landscape urbanization and its impacts on ecosystem services.

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### Table 8 Ecosystem services types and their contribution in the study area

| Ecosystem services | ESV (USD/yr) | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 |
|--------------------|-------------|------|------|------|------|------|------|
| Regulating         | 1866.19     | 1808.02 | 1747.85 | 1693.22 | 1678.31 | 1673.46 |
| Provisional        | 1733.13     | 1629.92 | 1495.34 | 1397.80 | 1351.70 | 1334.52 |
| Supporting         | 5317.06     | 5209.91 | 5079.51 | 4971.33 | 4924.34 | 4890.69 |
| Cultural           | 2677.43     | 2607.19 | 2383.45 | 2258.70 | 2170.16 | 2142.58 |

### Table 9 ESV provided by various LULC types from the year 1990 to 2040

| LULC type | ESV (USD/km²) | 1990 | 2000 | 2010 | 2020 | 2030 | 2040 | Change rate (%) |
|----------|---------------|------|------|------|------|------|------|-----------------|
| River    | 59.65         | 56.15 | 55.40 | 53.27 | 50.95 | 49.11 | -5.9 | -1.3 | -3.8 | -4.4 | -3.6 | -17.7 |
| Vegetation | 403.67        | 386.51 | 362.48 | 345.88 | 338.73 | 333.18 | -4.3 | -6.2 | -4.6 | -2.1 | -1.6 | -17.5 |
| Wetlands | 306.69        | 290.56 | 250.83 | 228.17 | 212.93 | 208.96 | -5.3 | -13.7 | -9.0 | -6.7 | -1.9 | -31.9 |
| Crop land | 223.57        | 190.68 | 168.68 | 146.35 | 139.30 | 138.61 | -14.7 | -11.5 | -13.2 | -4.8 | -0.5 | -38.0 |
| Built up | 144.77        | 181.70 | 214.18 | 239.43 | 252.25 | 256.07 | 25.5 | 17.9 | 11.8 | 5.3 | 1.5 | 76.9 |
| Bare land | 21.03         | 19.91 | 19.06 | 19.01 | 18.31 | 18.20 | -5.3 | -4.3 | -0.3 | -3.6 | -0.6 | -13.5 |
| Total    | 1159.38       | 1125.50 | 1070.61 | 1032.10 | 1012.45 | 1004.13 | -2.9 | -4.9 | -3.6 | -1.9 | -0.8 | -13.4 |

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Su et al. (2014) and Sahana et al. (2018) studied on urban spatial pattern and landscape change scenario. They noticed that urban secondary and primary core area were rapidly increased. The expansion of sub-urban fringe and scatter settlement areas also significantly noticed. Our analysis experienced that spatial process of urban expansion caused to shift of ESV in both urban core and sub-urban fringe areas. Many stakeholders are also affected both positively and negatively by the change of ESV. Natural habitat and wellbeing of other living organisms hampered due such ESV change.

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Global comparison of ESV

Costanza et al. (2014) reported the global terrestrial ESV during the year of 1997–2011 based on 1997-unit values. The global terrestrial ESV decreased by 28.82% due to LULC change. Our observation also reveals that total ESV in KUA was decreased by 21.04% during the phase 1990–2020 and will be decrease by 27.09% during the phase 1990–2040. Thus, the rate change in ESV in KUA was very close to global rate. The change rate of total ESV has been noted as very dynamic as it increased during first to second decadal phase, while it has slowed down during later decade. Globally, the shrinking of high ESVs areas like forests and wetlands was the main reasons for the drastic decrease in ESVs. During the phase 1997–2011, global vegetation and wetlands areas declined by 0.87% and 3.59% per year, respectively, while vegetation and wetlands areas in KUA decreased by 0.48% and 0.85% per year during the observed period of 1990 – 2020.

Policy implications

The wetlands and vegetation areas are the two main sensitive areas of natural capitals. In KUA we are losing 0.86% wetland area per year (during 1990 – 2020), which was slightly greater of global rate (Das et al. 2021) and two times greater than vegetation area shrinkage rate (0.45% per year). Therefore, priority in landscape policy formulation and planning should be emphasized to protect wetlands areas. Strict environmental influence analyses should be implemented, by focusing to conserve the agricultural areas located in the periphery of KUA. To improve the overall ESVs of KUA, targeted approach under various scenarios will be the most suitable. Although scenario analysis may not be the true representation of the future but it can act as supporting instrument in policy development and decision making (Guerra et al. 2017). A scenario analysis to improve the ESVs of KUA has been shown in Fig. 9. First, the probable pathways...
Fig. 7 Observed vs. Predicted ESVs in KUA for the year 2020

Fig. 8 Changes in the climatic factors in KUA over the last 30 years
were identified and a target was set with a fixed time-frame basis. To achieve the target, the design was made where the landscape planning and decision-making processes were considered. Different policies were assessed and the most practically implementable policy was chosen. After implementation of the policy, mid-term review needs to be done and based on the result, certain changes in the implementation, if needed, should be done. By this targeted scenario approach the ESVs of KUA should be improved and its effect will be felt by the society. Among the land uses, wetlands are most sensitive to changes in ESVs and most of the wetlands are situated along the eastern border of KUA. Protecting these wetlands and river banks from urban encroachment is necessary to increase the ESVs in future.

Nowadays, the management of ESs are also an important concept for sustainable landscape planning and decision-making process, because it can address the trade-off analysis and synergies between environment and socio-economic goals (Fig. 10). Trade-offs deals with the negative changes of ecosystem service value due to LULC change and synergies govern the improvement of ESs which should be appropriate in that region. The concept allows for better understanding to the policy makers (Kang et al. 2016). Rapid urbanization in KUA has trade-offs in supply of ESVs which need to be optimized by setting certain targets at the specified time periods. Different policy sectors like – environmental policy (climate and water policy), agricultural and rural development policy, regional development policy and strategies (biodiversity, forest strategy) have come out to enhance the ecosystem services. The regional development policy state that the potentiality of ecosystem services can be applied for landscape planning at regional and local level, which aims to enhancing, restoring or creating landscape and related services. With the consideration of the landscape scenario of Kolkata urban agglomeration, it is very essential to set landscape functions and capacity to fulfil not only for human demand but also other organisms.

The conversion of public as well as private open spaces to urban green spaces in KUA is a useful measure for protecting urban environmental quality. Urban green spaces produced ecosystem services can supply regulating services (biodiversity and climate regulation) and creates cultural services. It should be prioritizing on public areas like parks, sports fields, river banks and other riparian areas,
walkways and trails, communal shared gardens, street trees and bushes, nature conservation areas, and less conventional spaces in KUA. The ecosystem services provided by green space can improve the environmental condition, pollution, and congestion of the large urban areas like Kolkata urban agglomeration.

Limitations of the study

The main limitation of the present study would be associated with the LUCC map that obtained by support vector machine classification technique and the predicted LULC map obtained by CA-Markov chain model. Although, the CA–Markov model is very effective in simulating LULC pattern but it cannot precisely address human disturbances and spatial change of landscape scenario. Therefore, certain errors and uncertainties exist in the results of the simulation. Some of these errors are mainly described by the limitations of the image classification techniques and the internal doubtfulness in the model that result from the transition rules.

The estimation and prediction of ESVs based on the global coefficient values given by Costenza et al. (1997) was popular to decision makers and planners at broad geographical scales, but it require some field validation. Everard et al. (2019) calculated ESVs using field based rapid assessment of ecosystem services method of selected wetlands of Kolkata and Indian Gangetic delta after selecting some of the wetland sites. But site selection of each and every LULC types is very difficult and complicated task and needs some high-quality instrument. Therefore, the coefficient value of Costenza et al. (1997) is used for scenario based analysis and decision making when estimating and predicting ecosystem services at broad geographical scales because of quick assessment and the low cost for collecting field data.

Fig. 10 Trade-off analysis and synergies between environment and socio-economic goals
Conclusion

In Kolkata urban agglomeration, changes of ecosystem services under present and projected LULC from 1990 to 2040 has been analysed. The study determined the following outcomes as given below:

1. The total ESV has been decreased from $11,593.8 to $10,321.0 during the period of 1990–2020 with annual rate -0.37% and it will decrease from $10,321.0 to $10,041.3 during the period of 2020—2040 with annual rate of -0.15%.
2. The built-up land was increased from 450.86 km² to 754.69 km² with annual rate of 2.18% during the period from 1990 to 2020. It is also estimated that built-up land will be increased by annual rate 0.35% in between 2020 to 2040.
3. Globally, wetlands used to provide maximum ecosystem service value among the observed LULC types. Our analysis also illustrate that wetlands provided 26.45% of the total ESV in the year 1990 and decreased to 22.11% in 2020 and will be settled to 20.81% by 2040. Thus, shrinking of wetland area and wetland degradation play pivotal role for the decrease of ESV.
4. The grid wise spatial–temporal distribution of ESV was classified into five groups: very low (< $453.80), low ($453.81 - $619.60), moderate ($619.61 - $851.60), high ($851.61 - $1229.60) and very high (> $1229.61). We studied that 16.60% of grids are residing in very low ESV in 1990 and will be increase to 58.88% in 2040; and 2.69% of grids belongs to very high ESV and will be decrease in 2.35% in 2040.
5. Targeted scenario analysis approach can improve the ESVs in KUA which conceptualized the sustainable landscape planning and decision-making process. This approach is very important because it can address the trade-off analysis and synergies between environment and socio-economic goals.

The study regarding past, present and future ESVs as well as the scenario-based analysis to improve the future ESVs of KUA gives us a broad idea about the management of ESV. Although future research is needed to validate the findings of this research, the information of this study can also contribute for decision-making process in sustainable management of natural resources and provide some useful guideline for the improvement of environmental quality in the study landscape.

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