Sorker *et al. Environmental Systems Research* (2023) 12:32
https://doi.org/10.1186/s40068-023-00316-5

Environmental Systems Research

RESEARCH Open Access

Variations in ecosystem service value in response to land use changes in Dhaka and Gazipur Districts of Bangladesh

Raihan Sorker[1], Mohammad Wahidur Khan[2*], Alamgir Kabir[1] and Nowshin Nawar[3]

Abstract
Urban sprawl is a global phenomenon that has resulted in a substantial impact on ecosystem services. This study assessed how land use changes have affected the ecosystem services in Dhaka and Gazipur districts, two important economic centers of Bangladesh. This study analyzed changes in land use categories and their effects on ecosystem services during a thirty-year period, from 1990 to 2020, using LandSat data and published coefficient values. Additionally, a sensitivity analysis was undertaken to evaluate the ramifications of altering these coefficients on the resultant estimated values. The study revealed that in both Dhaka and Gazipur districts, the expansion of settlement areas and the reduction in tree vegetation cover have led to a significant decline in the overall value of ecosystem services. Over a 30-year timeframe, Gazipur experienced a more substantial loss in tree vegetation cover compared to Dhaka, whereas Dhaka witnessed a greater increase in settlement areas than Gazipur. Remarkably, during the most recent decade (2010–2020), the Gazipur district encountered heightened urban expansion and a more significant reduction in tree vegetation compared to Dhaka. The loss of the entire ecosystem service value was significant, amounting to USD 206.24 million for Dhaka and USD 381.27 million for Gazipur. This loss was primarily attributed to the decline in agricultural land, water bodies, rivers, and a reduction in tree vegetation. The study recommends that a more responsible land-use plan be created to protect tree vegetation, sustainable agriculture, and water bodies, which have the highest ecosystem service value in the study area. Overall, this study highlights the need for sustainable land-use techniques and offers insightful information about how urbanization affects ecosystem services in the investigated areas.

Keywords GIS, Remote sensing, Classification, Land use changes, Ecosystem service, Valuation

*Correspondence:
Mohammad Wahidur Khan
mwrkhan.es@gmail.com
[1]Department of Environmental Science, Bangladesh University of Professionals, Dhaka 1216, Bangladesh
[2]Ecosystem Services, Technische Universität Dresden, Dresden, Germany
[3]Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182, USA

Introduction

Ecosystem Services (ESs) are those goods and services that are directly or indirectly obtained from the ecosystems and are critical for the survival of human well-being (Millennium Ecosystem Assessment (MEA), 2005; Costanza et al. 1997, Costanza et al., 2014). Land use change, which is influenced by activities such as urbanization, deforestation, agriculture expansion, and infrastructure development, explicitly impact the conditions and fidelity of ecosystems, consequently affecting ecosystem services (ESs) (de Groot et al. 2012; Kindu et al. 2016; Li et al. 2007; Tolessa et al. 2017). Urbanization, economic development, and significant population growth are considered responsible for large-scale land fragmentation, and Land Use and Land Cover (LULC) change (Elmqvist et al. 2013; Arowolo et al. 2018). Since the last decade, the rate of transformation has increased dramatically (Vitousek et al. 1997; Chen et al. 2014) and management and conservation of land use is becoming a big challenge.

One of the promising approaches to promote conservation and more responsible decision-making is to put a "price" on natural assets (land use) while acknowledging ecosystems' environmental, economic, and social values (Lal 2003). Evaluating the effects of land use change on ESs and their valuation is considered an effective tool for decision-making (de Groot et al. 2012; Tolesa et al., 2018; Akber et al. 2018). Ecosystem Service Valuation (ESV) has been broadly accepted as a leading indicator for evaluating ecological environment changes and a topic of discussion in ecological economic research (Jiang et al. 2021; Fisher et al. 2009; Tianhong et al. 2010).

With the recent economic growth in Bangladesh, there has been a significant increase in the rate of land conversion, surpassing any previous rates observed. The government is introducing new policies to promote both economic development and environmental conservation. The development pattern of Bangladesh makes the implementation of these policies quite challenging, as economic activities are predominantly capital-centric (Arifeen et al. 2021). Dhaka division (includes Dhaka, Gazipur, Narayanganj, etc.) covers only 9% of the geographic area and contributes to around 40% of the total economy (Khan et al. 2023; Ahmed and Ahmed 2017). The higher economic opportunity, availability of jobs, and better lifestyle attract people to move to Dhaka from other areas. On the other hand, good connectivity (both road and waterway), availability of resources (electricity, gas, water), and cheap labor influence the setup of RMG, medicinal plants, and electronic factories in Gazipur (Arifeen et al. 2021). As such, it is not difficult to imagine that both Dhaka and Gazipur have experienced large-scale land fragmentation in the past years.

Previous studies have assessed the patterns of land use change in Dhaka city or metropolitan areas. For example, Byomkesh et al. (2012) identified the dynamics of green spaces in Dhaka whereas, Dewan et al. (2009) assessed the LULC in Dhaka metropolitan from 1960 to 2005 using the GIS technique. Rahman and Szabó (2021) conducted a study on the impact of land use and land cover changes on the urban ecosystem in Dhaka. Moniruzzaman et al. (2021) investigated the impact of LULC on surface runoff potential for Dhaka. Rai et al. (2017) summarized the studies between 1930 and 2015 on land cover and land use dynamics. Khan et al. in a recent study (2023), reported the distribution of green spaces in Dhaka metropolitan city. However, only a few studies have focused on Gazipur, which is another important economic power hub for the nation. Arifeen et al. (2021) explored the urban expansion and driving factors for sustainable development in Gazipur. Rahman et al. (2022) studied historical LULC from 2005 to 2020 in Bhawal National Park, Gazipur. However, different studies adopted various estimation methods, making it quite challenging to compare them with each other, and only a few assessed the loss of ESV due to land use change. To address these gaps in the existing literature, this study seeks to answer the research question: How have urban sprawl and land use changes in Dhaka and Gazipur districts of Bangladesh impacted ecosystem services over the past three decades (1990–2020)?

Therefore, the researchers attempted to minimize the study gap and aimed to assess the impact of land use on ecosystem services in Dhaka and Gazipur districts of Bangladesh over a three-decade span (1990–2020), emphasizing the need for sustainable land-use strategies. The specific objectives of this research are as follows: (i) to characterize and compare the dynamics of Land use and Land cover (LULC) changes in the Dhaka and Gazipur districts, and (ii) to estimate the variations in ecosystem service values (ESV) in response to LULC changes from 1990 to 2020. The findings of the study will be useful to policymakers in the formulation of policy-stabilizing ESVs in the study areas.

Materials and methods

Study area

The study considered Dhaka (23°58′ to 23° 90′ N and 90°33′ to 90°50′ E) and Gazipur (23°58′ to 23° 90′ N and 90°33′ to 90°50′ E) districts as the study area (Fig. 1). Both these areas are commercially and administratively important, and the majority of the industries are located there. The Daily Star (2022) reported that at least one-third of the total garments in Bangladesh are located in Gazipur. These two regions are the most common destinations for migratory workers, and every year, a large population migrates to these regions for better economic and

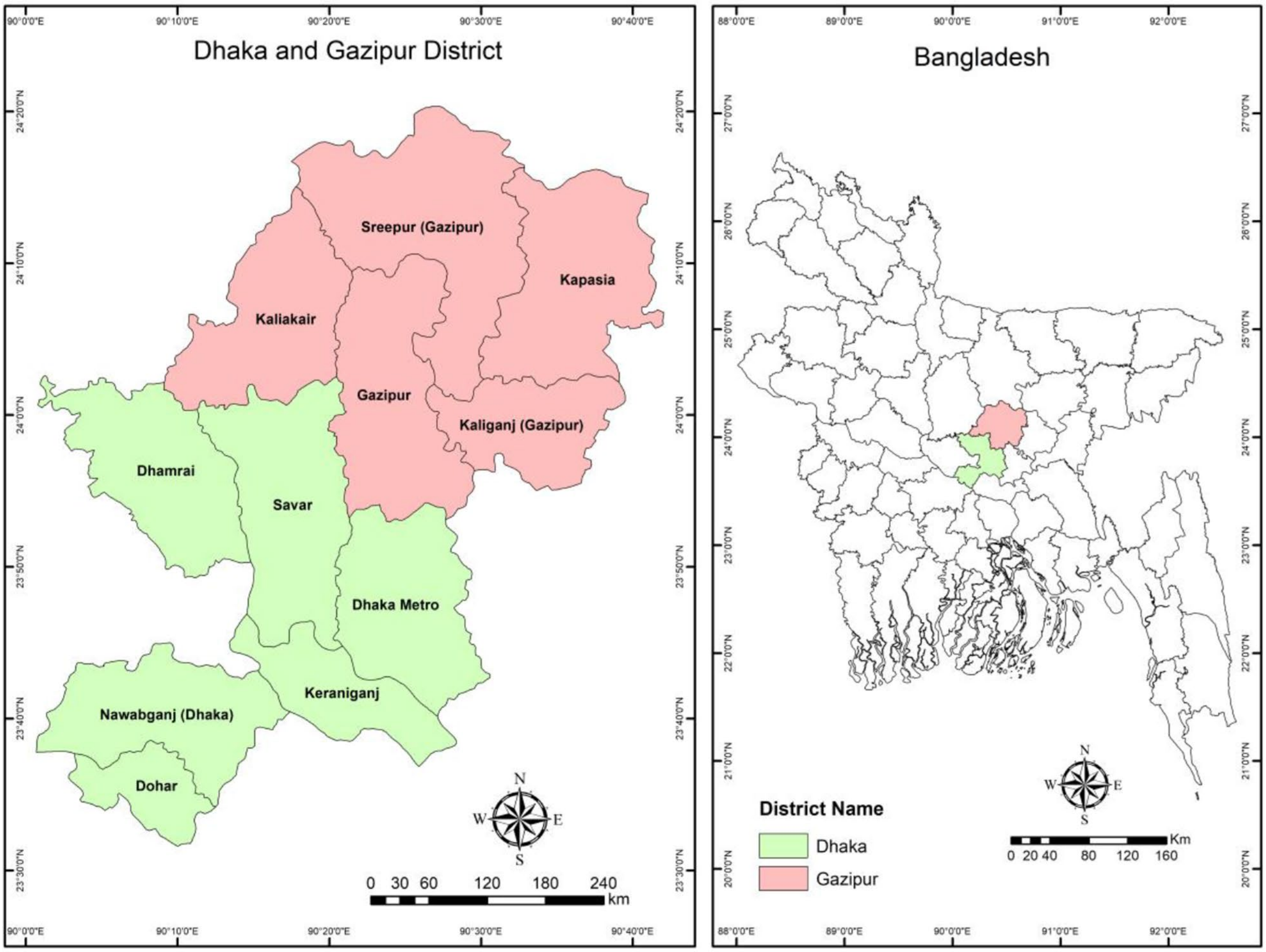

Fig. 1 Map of the study area

livelihood opportunities (Dewan et al., 2008; Arifeen et al. 2021).

The study areas are surrounded by several major river systems, such as Padma, Buriganga, Turag, Shitalakshya, Balu, Dhaleshwari, and some other small rivers. In Dhaka, the predominant crops are rice and wheat, while potatoes and beans thrive during the winter season. The city also accommodates various industrial sectors, including the Dhaka Export Processing Zone (DEPZ), brickfields, tanneries, textiles, and chemical industries (Bhuiyan et al., 2021). It's also a socio-cultural epicenter and witnesses significant migration from climate-vulnerable rural areas (Zinia and McShane 2021). Moreover, rapid urbanization has led to the encroachment of wetlands and green spaces. Dhaka city has only 8% tree-covered lands, well below the recommended 20%, and merely 2% healthy green space in 2020 (Rahman and Zhang 2018; Nawar et al. 2022). Urban expansion poses a severe threat to Dhaka's environment, biodiversity, and urban ecosystem. The Sal (*Shorea robusta*) Forest, characterized by deciduous vegetation, is a valuable natural asset of Bangladesh, encompassing the Gazipur district (Sayed et al. 2015). Gazipur is also well known for diversified agricultural products including rice, wheat, jute, vegetables, flowers, dairy farming, poultry, fish farming, and mushroom cultivation. Different anthropogenic activities, for example, conversion of agricultural land, deforestation, and urbanization, have significantly altered the natural ecosystem of these areas (Rahman and Szabó 2021; Arifeen et al. 2021).

Data acquisition

The study was conducted using 30-meter resolution Landsat 4–5 Thematic Mapper (TM) for the years 1990, 2000, and 2010; and Landsat 8 (OLI/TIRS) for 2020 (Table 1). Satellite imagery of the winter was chosen intentionally to acquire cloud-free satellite images or at least to have a very minimum cloud cover. Satellite images were collected from https://earthexplorer.usgs.gov/, the website of the United States Geological Survey (USGS). The Worldwide Reference System (WRS), which divides the earth into numerous tiles with different but

Table 1 Metadata of satellite image

Satellite Data	Spatial Resolution (meters)	Acquisition Date	WRS path and row	Cloud cover (%)	Day/Night
Landsat 4–5 TM	30 × 30	1990/01/07	137 043	3	Day
Landsat 4–5 TM	30 × 30	1990/01/07	137 044	3	Day
Landsat 4–5 TM	30 × 30	2000/01/19	137 043	0	Day
Landsat 4–5 TM	30 × 30	2000/01/19	137 044	0	Day
Landsat 4–5 TM	30 × 30	2010/01/30	137 043	0	Day
Landsat 4–5 TM	30 × 30	2010/01/30	137 044	0	Day
Landsat 8 OLI/TIRS	30 × 30	2020/01/26	137 043	2	Day
Landsat 8 OLI/TIRS	30 × 30	2020/01/26	137 044	2	Day

Table 2 Identified land use categories and their proxy biomes identified in the literature (Costanza et al., 2014) and the corresponding ecosystem value coefficients

Land use	Equivalent Biome	Ecosystem service coefficient (US $ ha^{-1} per year)
Agricultural land (cultivated land, seasonal cultivated land, open and fallow Land)	Cropland	5567
Water body (permanent and temporary open water, lakes, canals, artificial reservoir)	Wetlands	140,174
River (Major rivers)	Rivers	12,512
Tree vegetation (Sal forest, deciduous forest, mixed forest, orchard)	Tropical forest	5,382
Urban fabric (residential, commercial, industrial, road, streets, char lands)	Urban	0

unique paths and row numbers, was used for the precise extraction of satellite images from the study area. The specific row and path numbers of the study areas are WRS path 137, row 43, and 44. The characteristics of the collected image are listed in the following Table 1.

Data processing and analysis

Land use classification

The study adopted GIS and Remote Sensing techniques for estimating the landuse change and calculating ESs values. The first step of land use classification was image pre-processing, which involved radiometric enhancement and atmospheric correction of the satellite image done using ENVI 5.3 (https://www.l3harrisgeospatial.com/) software. This process helped to avoid interferences in spectral information. The maximum likelihood-supervised classification technique was adopted using ArcGIS 10.3 (https://www.esri.com/), which is the most common method used in the analysis of remotely sensed images (Richards 2013). Thus, five major land use classes were identified in the study area: agricultural land, water body, river, tree vegetation, and urban fabric (Table 2).

As we collected satellite images of the winter season, the time for harvesting and field preparation, agricultural land could often appear as fallow land during land classification. Therefore, those lands have been classified as agricultural land. On the other hand, the waterbody and river have quite similar spectral signature appearance that could result in misclassification between the river and waterbody in the classification process. To overcome this issue, a separate layer of the river was used as a mask during the classification. The river always changes its courses, therefore, it was also necessary to modify the river layer so that it could exactly match the course of the river.

Although all forests in Bangladesh are now being designated as protected areas, historical forest management policies, during the colonial and Pakistani ruling periods, were primarily focused on revenue generation. (Islam and Hyakumura 2019). During the 1980s, a large portion of the forest was allocated to rubber plantations and social forestry programs, which made land ownership and land-user-right complicated and unclear. Nonetheless, orchards are found within the forest, posing a challenging task in terms of distinguishing them from the forest in satellite image analysis. Therefore, these orchards were also included in the tree vegetation class. Moreover, there is mixed cultivation being practiced inside and near the periphery of the forest.

The urban fabric includes all artificial infrastructure, for example, buildings, roads, bridges, industry, factories, and char Island. Char Island is a special type of land that has distinguished characteristics. These islands are mainly sandy areas and have very low productivity and are randomly used for seasonal cultivation. Conversely, a limited number of char areas have been inhabited by human populations, although such habitation remains relatively uncommon. However, there is a practice among the illegal land developers to encroach on the island, make it (*to a certain degree*) stable, and promote housing activity, especially among the low-income generating people. The chars provide distinguished ESs, which cannot be provided by other lands, and the conversion of the island into other land classes obsolete those services. As the char areas are being used more for accommodation rather than agriculture, we included them in the urban fabric.

However, a total of 300 training samples were taken from each of the five classes; further, the samples were merged into one signature file that represented the specific class. Finally, the area was classified into five classes using the supervised classification technique, and the area covered by each of the five classes was calculated using the geometry feature in ArcGIS 10.3. Previous studies by Akber et al. (2018), Gashaw et al. (2018), Temesgen et al. (2018), Khan et al. (2023), etc. also adopted the same techniques for land use classification.

Accuracy assessment

Assessing the accuracy is an important step to identify the uncertainties associated with satellite image-based land-use classification, as the uneven distribution of data in the maximum likelihood classification can cause the misclassification of the pixels (Fang et al. 2006). "Ground truthing," a data collection method conducted on-site and subsequently compared with produced classification, is commonly used for accuracy assessment. In the present study, the ground truthing method was adopted for 2020 where 250 well-distributed point locations were used for collecting first-hand land use information. A historical image from the Google Earth Engine was used to determine the accuracy of the classification from 2000 to 2010. Although the reference data for 1990 was not provided by Google Earth, it was compared with the reference image of 2001.

The collected information was used for developing an error matrix where overall accuracy was determined by validating classified images against actual land use. The Kappa coefficient, a statistical approach, was conducted to determine how reliable the classification was. A higher Kappa value indicates a greater similarity to the real world on a scale ranging from −1 to +1. Typically, values closer to 1 are associated with greater accuracy (Landis and Koch 1977).

Assessment of ecosystem services value

The classified land use of the study area was compared with five separate (most representative) biomes in estimating the ESs value produced by Costanza in their ESs valuation technique (Costanza et al. 1997). It is one of the most widely used secondary valuation techniques for transferring the previously measured estimation from the novel (primary) valuation in one geographical region to other regions with comparable variables (Plummer 2009; Yi et al. 2017). Costanza et al. (2014) have provided the most comprehensive set of ecosystem service coefficients for estimating ecosystem service value for 16 major biomes. In this study, we have focused on estimating the value of ecosystem services within five specific biomes. Other biomes, such as Open Ocean, Estuaries, Seagrass/Algae Beds, Coral Reefs, Temperate/Boreal forest, Grass/Rangelands, Tidal Marsh/Mangroves, Swamps/Floodplains, Desert, Tundra, Ice/Rock, do not apply to the study area. The most representative biomes were considered a proxy for different land uses in the study area, and the updated monetary value calculated by Costanza et al. (2014) was followed for these land-use classes (Table 2). To determine ecosystem service value, some studies utilized local-level ecosystem service coefficient data (Chuai et al. 2016; Kindu et al. 2016; Xue et al., 2018). However, there are limitations to the use of published coefficient values. These values rely on subjective judgments about the value of ecosystem services, which can vary depending on the individual or group making the assessment (Costanza et al. 1997). The coefficient reduces the complexity of ecosystems and their services to a single monetary value, potentially failing to capture their true significance accurately. Moreover, it overlooks the specific social, cultural, and ecological contexts within which ecosystem services function that can significantly influence their worth. Therefore, the applicability of the Costanza coefficient may be limited, especially in cases where ecosystem services are challenging to quantify or when there is substantial uncertainty surrounding their valuation (de Groot et al. 2012).

For the ESV assessment of each identified landuse class, the following equation was used (Eq. 1) where $\boldsymbol{A_K}$ stands for the area (ha) and $\boldsymbol{VC_K}$ represents value coefficient (US \$ ha^{-1}yr^{-1}). Moreover, the total ecosystem service for a particular year was calculated by aggregating all of the individual ES from the equation. Previous studies by Akber et al. (2018); Arowolo et al. (2018); Tolessa et al. (2017); and Kreuter et al. (2001) also used the same method.

$$\boldsymbol{ESV} = \sum \boldsymbol{A_K} \times \boldsymbol{VC_K}$$

The change in ESV in different periods (1990–2000, 2000–2010, 2010–2020) was calculated using the following Equation (Eq. 2).

$$\mathbf{ESVchange}\,(\%) = \frac{\boldsymbol{ESV_{recentyear}} - \boldsymbol{ESV_{initialyear}}}{\boldsymbol{ESV_{initialyear}}} \times 100$$

Sensitivity analysis

This valuation method used different biomes as a proxy for different land uses, although they did not match exactly. Considering these uncertainties, a coefficient of sensitivity was analyzed using the standard economic concept of elasticity to determine how the applied coefficients affected our estimation of changes in the adjusted valuation coefficient. The value coefficients for tree vegetation, agricultural land, waterbody, and river were adjusted by 50%, and the corresponding coefficient of sensitivity (CS) was calculated using the following Eq. 3, which validates the robustness and reasonability of ESV estimation (Kreuter et al. 2001; Tolessa et al. 2017; Li et al. 2007; Hu et al. 2008).

$$\mathrm{CS} = \frac{(ESVj - ESVi)/ESVi}{(\mathbf{v}Cjk - vCik)/vCik}$$

Where CS is the coefficient of sensitivity, $ESV_{i,}$ and ESV_j are the initial and adjusted total estimated ecosystem service values, respectively, and VC_{ik} and VC_{jk} are the initial and adjusted value coefficients (adjusted to the upper 50% and lower 50%) ($\$ha^{-1}yr^{-1}$) respectively, for land use type 'k'. The estimation of ecosystem service value is robust when the ratio is less than one and indicates elasticity when the ratio is greater than one (Zhao et al. 2004).

Results

Spatiotemporal evolution characteristics of land use

Land use change from 1990 to 2020 analyzed from the satellite image classification is illustrated in Fig. 2 and the categories are also shown in Tables 3 and 4. The research found a decreasing trend of land area covered by tree vegetation and waterbody, with an increase in urban fabric (settlements). Moreover, a fluctuation (temporary decrease and increase) of agricultural land in both districts, Gazipur and Dhaka, was observed over the tenure. Between 1990 and 2015, tree vegetation reduced from 66142.9 to 36639.2 ha (approx. 21% decrease) and 84655.04 to 40989.15 ha (approx. 25% loss) in Dhaka and Gazipur respectively. It could be noted here that Dhaka experienced a loss (9.8%) of tree vegetation between 1990 and 2000. Simultaneously, urban fabric increased from 21616.97 ha to 53140.12 ha (around 21.3%) in Dhaka and 24961.85 to 61914.05 ha (approx. 21%) in Gazipur during the study period. Agriculture, waterbodies, and river areas underwent a decrease of 0.8, 0.1, and 0.3%, respectively, in Dhaka. The maximum loss (2.9%) of agricultural land was observed between 2000 and 2010 whereas the maxim loss of around 0.14%, the greatest loss of waterbody happened between 1990 and 2000. (Tables 3 and 5). In Gazipur, the declination of tree vegetation and water bodies was higher than that in Dhaka. Waterbody and river areas were reduced by around 0.8 and 0.3%, respectively between 1990 and 2020. It is worth noting, the agricultural land increased by about 12% between 1990 and 2000 and since then kept declining. However, the overall agricultural land increased by around 4% (Tables 4 and 5).

According to the landuse classification and mapping (Fig. 2; Supplementary Information (SI), Fig A1), tree vegetation was the dominant land use in 1990, and dense vegetation was observed occupying the area between the northeast and southwestern part of Dhaka. Between 2000 and 2010, settlements started to flourish in the eastern part of Dhaka and tree vegetation was converted to urban areas in that part rapidly (SI Figure A1, A5). By 2020, the east side of Dhaka was covered by urban fabrics, the north was dominated by agricultural land, and tree vegetation existed in the south (Fig. 2; SI Figure A1, A3, A5). In Dhaka, the agricultural land increased slightly between 2000 and 2010 and for the rest of the periods the size of the agricultural land decreased. However, the river area decreased constantly, especially the river Buriganga got narrowed near Dhaka city. Rivers near the Dhamrai and Nawabganj upazila reduced in the year 1990–2000 (Fig. 3).

The Gazipur showed a decreasing pattern in tree vegetation, river, and waterbody, whereas the urban fabric area increased (Fig. 4; Table 5). In 1990, almost half of the geographic area (47.9%) was covered by tree vegetation, which reduced to 23% over the years. The most conversion of the tree vegetation to other land used happened between 2010 and 2020, which is depicted in Fig. 4, (SI Figure A2). Although the agricultural land increased significantly (around 12%) from 2000 to 1900, the overall change was recorded as 5% from the initial amount. However, the settlement increased continuously and became the second dominant landuse cover in 2020, only second to agriculture in Gazipur.

Confusion matrix for accuracy assessment

To assess the overall accuracy of the land use classification, a confusion matrix was developed and according to the estimation, the overall accuracy (OA) was reported as 91.2%, 90.8%, and 89.2% for 2000, 2010, and 2020 respectively for Dhaka. Whereas in Gazipur the accuracy is 89.2%, 88.8%, and 88.4% for those years, respectively (SI, Table A1, and A2). In these cases, the accuracy level is above 85%, which is the minimum accuracy-level standard (Anderson et al. 1976). For the most recent years, 2020, the accuracy was assessed through extensive, first-hand ground truth data. However, for other years, Google Earth imagery was used as a reference for accuracy assessment. The summary of the confusion matrix is presented in Table 6, and detailed calculations could be found in Table A1 on SI.

Estimated ecosystem service value

Changes in ESV for the land-use categories were calculated by multiplying the estimated changes in the land area for each category by the respective ecosystem service value coefficients reported by Costanza et al. (2014). The total value of ecosystem services declined from US$ 853.19 to US$ 646.95 million in Dhaka whereas in Gazipur the value decreased from US$1192.09 to 810.82 million between 1990 and 2020 (Tables 7 and 8). The conversion of tree vegetation to other land use and the

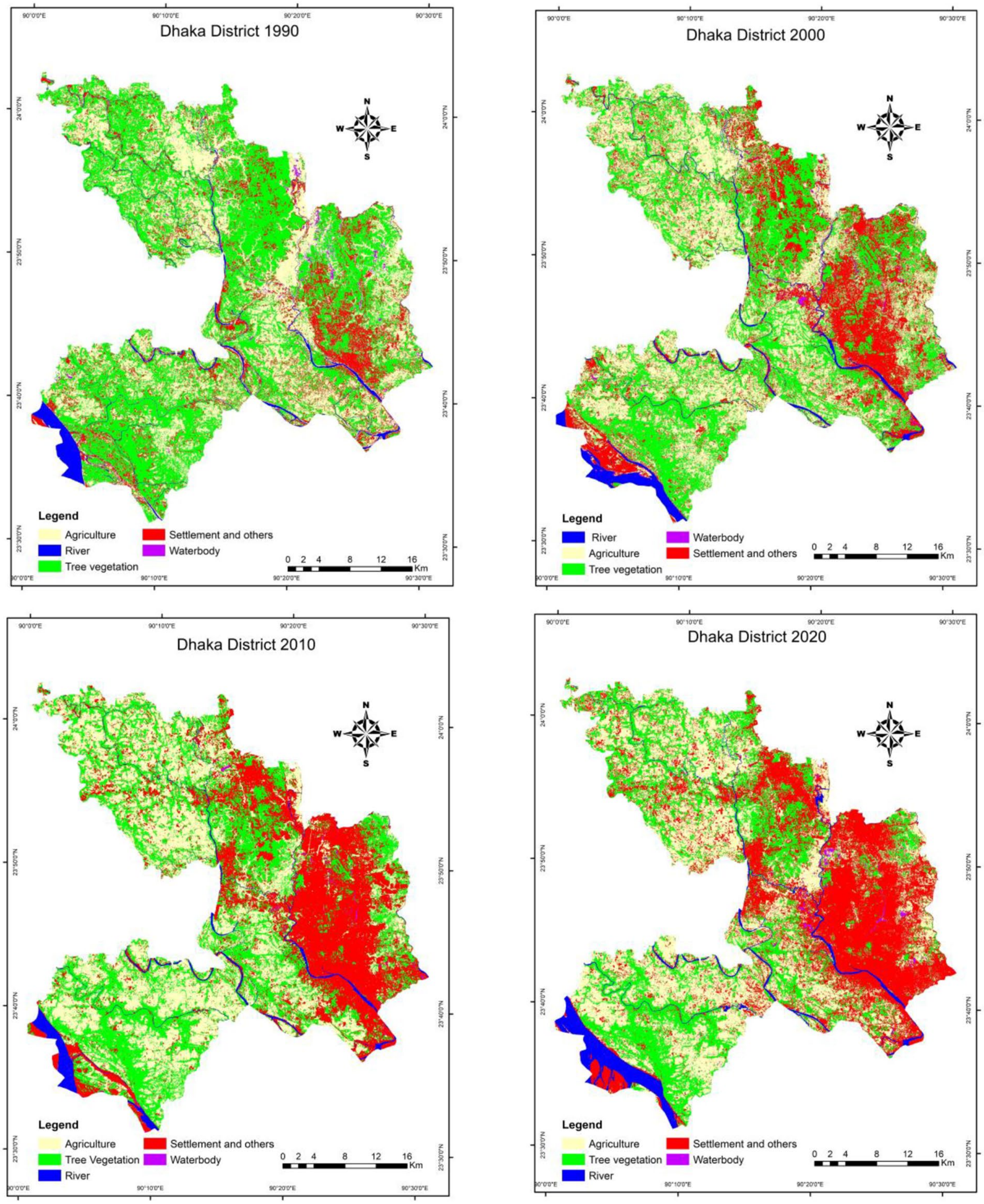

Fig. 2 Land Use change maps of Dhaka district from 1990–2020

expansion of urban areas was the major contributor to the ESV decline in the study area.

The ESV of tree vegetation and water body decreased in Dhaka with an estimated loss of US$ 158.79 and US$ 33.57 million, respectively. ESV of agriculture was estimated to be the highest in 2000 (US$ 314.81 million) and the lowest in 2010 (US$ 290.94 million). However, the economic value of ecosystem service loss associated with land use changes in agriculture and rivers was US

Table 3 Total estimated area (ha) of each land-use category in Dhaka district from 1990 to 2020

Class	1990		2000		2010		2020	
	Area	%	Area	%	Area	%	Area	%
Tree vegetation	66142.99	44.73	51586.17	34.89	47174.2	31.9	36639.2	24.78
Agriculture	54226.59	36.67	56548.68	38.24	52261.03	35.3	53018.61	35.86
Water body	953.65	0.64	747.11	0.51	731.6	0.5	714.16	0.48
Settlement	21616.97	14.62	34796.29	23.53	43554.82	29.4	53140.12	35.94
River	4927.82	3.33	4189.77	2.83	4146.37	2.8	4355.93	2.95
Total	147868.02	100	147868.02	100	147868.02	100	147868.02	100

Table 4 Total estimated area (ha) of each land-use category in Gazipur district from 1990 to 2020

Class	1990		2000		2010		2020	
	Area	%	Area	%	Area	%	Area	%
Tree vegetation	84655.04	47.87	62610.55	35.40	56727.49	32.08	40989.15	23.17
Agriculture	62959.77	35.60	83552.31	47.24	77719.69	43.95	71524.72	40.43
Water body	2601.18	1.47	1625.81	0.92	1605.95	0.91	1263.41	0.71
Settlement	24961.85	14.09	27601.45	15.60	39359.8	22.22	61914.05	35.00
River	1707.73	0.97	1495.45	0.84	1472.64	0.83	1194.24	0.67
Total	176885.57	100	176885.57	100	176885.57	100	176885.57	100

Table 5 Area and percentage changes of land use in Dhaka and Gazipur district

	Class	1990–2000		2000–2010		2010–2020		Total 1990–2020	
		Area	%	Area	%	Area	%	Area	%
Dhaka	Tree vegetation	-14556.8	-9.83	-4412	-2.98	-10,535	-7.13	-29503.8	-19.95
	Agriculture	2322.09	1.58	-4287.7	-2.9	757.58	0.5	-1207.98	-0.82
	Water body	-206.54	-0.14	-15.51	-0.01	-17.44	-0.01	-239.49	-0.16
	Settlement	13135.21	8.89	8753.3	5.92	9631.66	6.5	31520.1	21.32
	River	-738.05	-0.5	-43.4	-0.03	209.56	0.14	-571.89	-0.39
Gazipur	Tree vegetation	-22044.5	-12.47	-5883.06	-3.31	-15738.3	-8.91	-43665.9	-24.7
	Agriculture	20592.54	11.63	-5832.62	-3.28	-6194.97	-3.52	8564.95	4.83
	Water body	-975.37	-0.55	-19.86	-0.01	-342.54	-0.19	-1337.77	-0.76
	Settlement	2679.45	1.51	11696.01	6.62	22620.28	12.78	36995.74	20.91
	River	-212.28	-0.12	-22.81	-0.01	-278.4	-0.16	-513.49	-0.29

$ 6.72 and US $ 7.16 million over the period. (Table 7; Fig. 4).

Due to the gain of the agricultural land, the ESV of the agricultural land class increased in the Gazipur district. On the other hand, the conversion of tree vegetation, waterbody, and river resulted in an ESV loss of US $ 235.01, US $ 187.52, and US $ 6.42 million in Gazipur. The ecosystem value of the river depicted the highest value of US $ 21.37 million in 1990, which dropped to US $ 14.94 million in 2020. The ESV of agricultural land shows a total increase of US $ 47.68 million. The highest loss (US $ 3.48 million) in the ESV of the river was recorded between 2010 and 2020 (Table 8; Fig. 5). Overall, the total loss in the ecosystem services value of Dhaka and Gazipur were 24.2 and 31.9% respectively.

Coefficient of sensitivity

The coefficient of sensitivity (CS) was calculated by adjusting its value to ±50% to analyze the impact of input parameter uncertainty in the calculation. The representation of the result using an alternative coefficient to determine the entire ecosystem service of the study area from 1990 to 2020 is presented in Table 9. The CS ranged from 0.31 to 0.42 for tree vegetation, 0.35 to 0.46 for agriculture, 0.14–0.16 for waterbody, and 0.7–0.8 for rivers in Dhaka district. For the Gazipur district, the CS value ranged from 0.27 to 0.38 for tree vegetation, 0.29–0.49 for agriculture, 0.22–0.31 for waterbody, and 0.2 for rivers.

The calculated CS values were far away from unity and closer to zero, which indicated that the total ecosystem services value estimated in this study area was comparatively robust and inelastic apropos of the value coefficients. The degree of estimates of ESV can considerably be affected by highly undervalued or overvalued coefficients over time. The adjustment of the value coefficient of agriculture, tree vegetation, waterbody and rivers did not have a significant impact on the overall ecosystem service values. The reason behind this is their very low

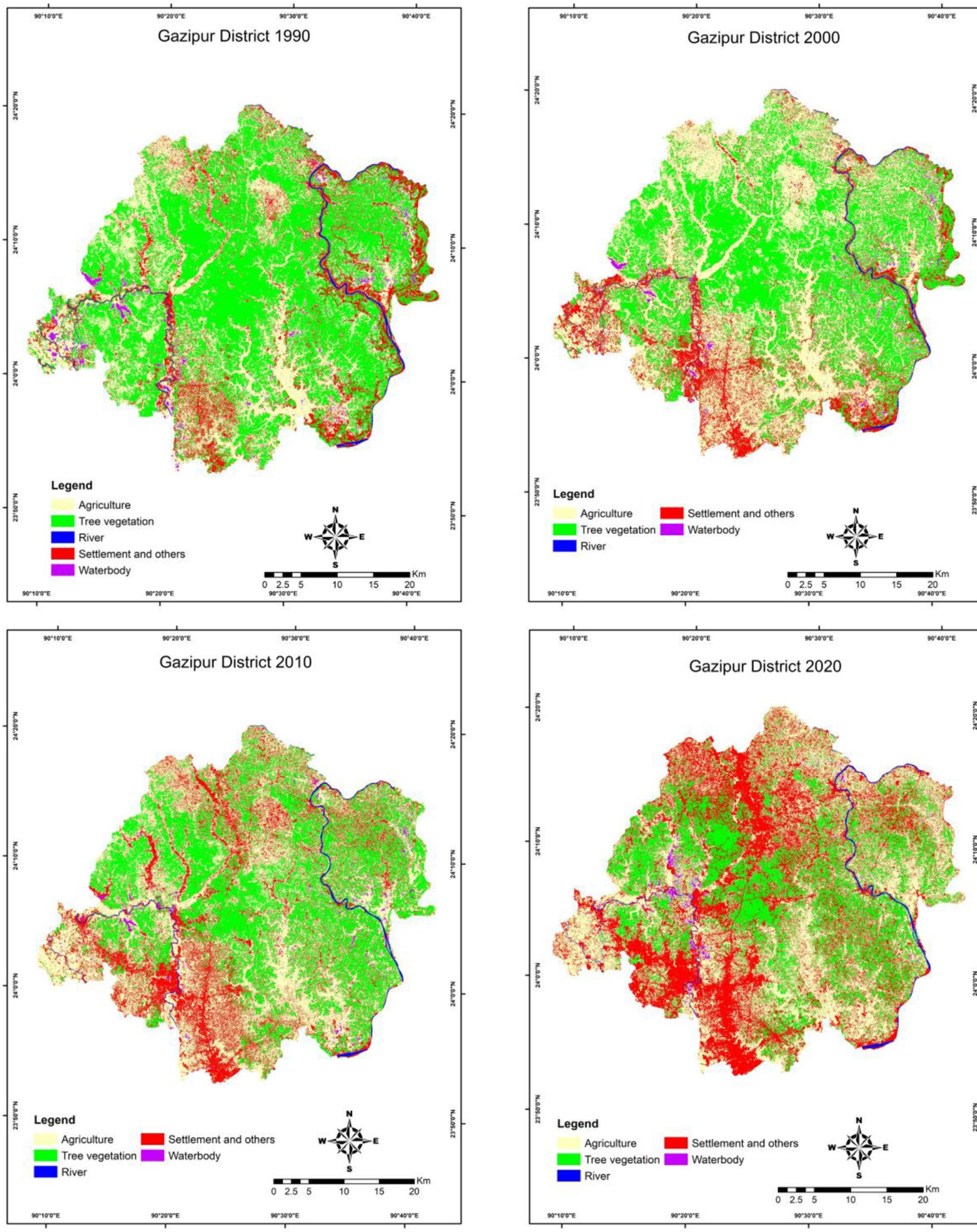

Fig. 3 Land Use change maps of Gazipur district from 1990–2020

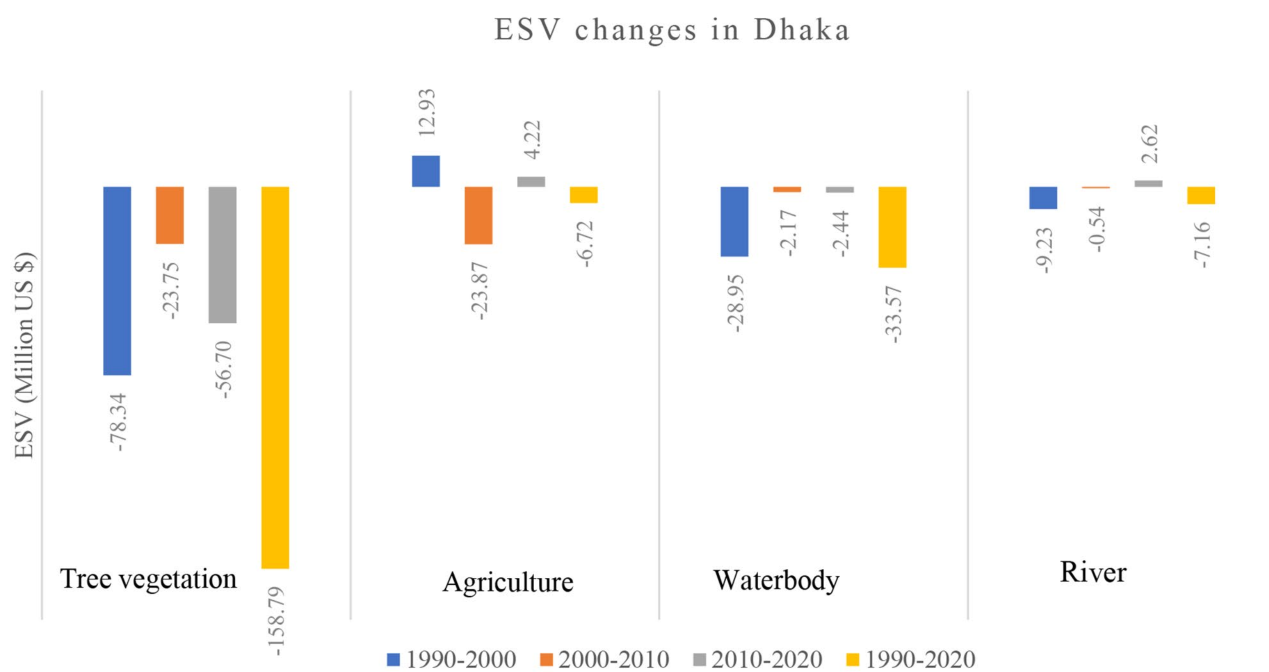

Fig. 4 ESV changes (million US $) in Dhaka

Table 6 Overall accuracy (OA) and Kappa value of Dhaka and Gazipur district (2000–2020)

Area	2000		2010		2020	
	OA	Kappa	OA	Kappa	OA	Kappa
Dhaka District	91.2	0.89	90.8	0.88	89.2	0.86
Gazipur District	89.2	0.86	88.8	0.86	88.4	0.85

Table 7 Ecosystem service value (million US $) of Dhaka district from 1990 to 2020

Class	1990		2000		2010		2020	
	ESV	%	ESV	%	ESV	%	ESV	%
Tree vegetation	355.98	41.72	277.64	37.04	253.89	36.31	197.19	30.48
Agriculture	301.88	35.38	314.81	42	290.94	41.61	295.15	45.62
Water body	133.68	15.67	104.73	13.97	102.55	14.67	100.11	15.47
River	61.66	7.23	52.42	7	51.88	7.42	54.5	8.42
Total	853.19	100	749.59	100	699.26	100	646.95	100

Table 8 Ecosystem service value (million US $) of Gazipur district from 1990 to 2020

Class	1990		2000		2010		2020	
	ESV	%	ESV	%	ESV	%	ESV	%
Tree vegetation	455.61	38.22	336.97	32.13	305.31	31.11	220.6	27.21
Agriculture	350.5	29.4	465.14	44.35	432.67	44.08	398.18	49.11
Water Body	364.62	30.59	227.9	21.73	225.11	22.94	177.1	21.84
River	21.37	1.79	18.71	1.78	18.43	1.88	14.94	1.84
Total	1192.09	100	1048.71	100	981.51	100	810.82	100

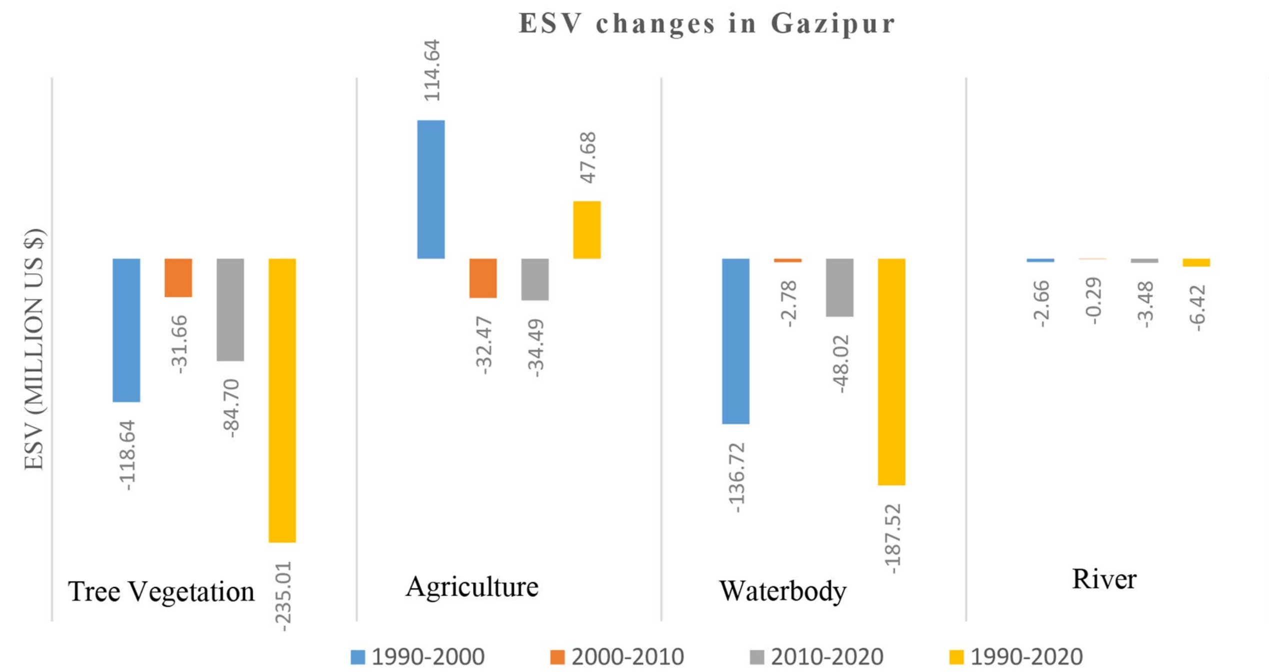

Fig. 5 ESV changes (million US $) in Gazipur

Table 9 Coefficient of sensitivity resulting from adjustment of ecosystem value coefficient for Dhaka and Gazipur district (1990–2000)

	Class	1990	2000	2010	2020
Dhaka District	Tree vegetation ± 50%	0.42	0.37	0.36	0.31
	Agriculture ± 50%	0.35	0.42	0.42	0.46
	Water body ± 50%	0.16	0.14	0.15	0.16
	River ± 50%	0.07	0.07	0.07	0.08
Gazipur District	Tree vegetation ± 50%	0.38	0.32	0.31	0.27
	Agriculture ± 50%	0.29	0.44	0.44	0.49
	Water body ± 50%	0.31	0.22	0.23	0.22
	River ± 50%	0.02	0.02	0.02	0.02

contribution to the total ESV and also the small value of those land classes.

Discussion

A bulky value of ecosystem service loss indicates the fragile ecosystems in the study area, as between 1990 and 2020, Dhaka and Gazipur lost around US $ 203 and US $ 390 million worth of ESs. Analyzing the ESV loss pattern, it appears that the main reason for ESV loss is the conversion of tree vegetation to other LULC. However, the decrease in water bodies and river areas also contributed to the reduction of ESV. The findings from our study align with findings from other research and could be summarized in the following statements: (i) overall the tree and vegetation, river, waterbody, and agricultural land decreased whereas urban fabric area increased constantly; (ii) in Dhaka, agricultural land did not change significantly, whereas in Gazipur it was observed larger change; (iii) a large portion of the tree and vegetation area were converted into urban fabric; (iv) Though Gazipur gained agricultural land compared to the amount in 1990, it got decreased if compared with the other years (2000 & 2010). It is important to keep in mind that LULC change is a complicated, dynamic, and nonlinear process that is influenced by natural and artificial factors and does not necessarily follow a similar pattern (Rahman and Szabó 2021; Akber et al. 2018).

LULC dynamics and its impact on ESV variations

According to analysis, the tree vegetation in Dhaka reduced to around 50% in the last 30 years, specifically between 1990 and 2000 the tree vegetation decreased to a maximum of around 10%. During the same period, urban areas increased by around 9%, and agricultural land increased by around 1.5%. In Dhaka metropolitan area, the trees and vegetation disappeared and the urban areas started to appear as the dominant land use during this time (Figure A1, A5 of SI). According to the data from the World Bank (2012), the population growth between 1990 and 2000 was 2.8% (which was one of the highest rates) and Bangladesh also started to enter the industrialization era. Moreover, the establishment of Bangladesh Small and Cottage Industries Corporation (BSCIC) also promoted further industrialization along the Turag riverside (Sultana et al. 2012). Those factors exerted an influence on the demand for the construction of new buildings and infrastructure, thereby elucidating the elevated rate of urban development during that particular period. In the following decades, especially between 2010 and 2020, Bangladesh experienced even faster industrial and economic growth, which caused rapid land use changes in the study area. Dhaka and Gazipur as economic hubs play a significant role in the transformation of Bangladesh to become the most successful least developed country in 2020.

Gazipur, which was once well known for Sal Forest (Shorea robusta) and agricultural cultivation, is now famous for accommodating ready-made garment industries, electronic factories, and other small and large-scale industries. Sal forest, a unique and important ecological resource of Bangladesh stretched throughout Shreepur, Gazipur Sadar, and Kapasia upazila of Gazipur, decreased due to increasing demand for food (agriculture), timber, space for housing, and commercial infrastructure (Abdullah et al. 2019, Uddin & Gurung, 2008; Dewan and Yamaguchi 2009). Illegal logging, which is reported as another dominant factor for forest loss- contributes significantly to the conversion of the forest. According to Rahman et al. (2010), illegal logging was responsible for 12% of forest loss. The primary reasons for the increase in settlements in both districts were migration, centralization, and industrialization (Dewan et al., 2009). The change in the landuse of each class in Gazpur is illustrated in Figures A2, A4, A6 of SI.

Our study shows that, in the study area, initially between 1990 and 2000, Dhaka and Gazipur gained some agricultural lands, which were again lost in the following years. In Dhaka, agricultural land increased by around 1.6% between 1990 and 2000 and then decreased by 2.3% (Table 4). However, the conversion of agricultural land followed a different pattern in Gazipur. Between 1990 and 2000, the land increased by a record of around 11.6% which was then followed by a decrease of 3.2% and 3.5% between 2000 and 2010 and 2010 to 2020 respectively. Hasan et al. (2013) estimated that between 2000 and 2010 agricultural land decreased by 0.6% per year which is higher than our estimation but supports the findings of our research. The analysis also shows that agricultural land increased due to the conversion of trees and vegetation, whereas agricultural land decreased due to their conversion into the urban fabric. Figure A4 of SI illustrates the conversion of Agricultural land cover in Gazipur from 1990 to 2020, which indicates that Gazipur Sadar lost the highest agricultural land.

Another important natural resource, river, decreased in both Dhaka and Gazipur over the past years though the change was very insignificant (<0.5%). From analysis, it is evinced that Dhaka has lost slightly more river area compared to Gazipur (Tables 4 and 5, SI Figure A7 to A10). Shrinking of the river area is a nationwide phenomenon and not surprising that the rivers of the study area are suffering from it. It is estimated that Bangladesh lost around 10,000 sq km of the river from 1985 to 2015 (IUCN 2016). However, this study does not necessarily represent the navigability crisis that rivers are currently experiencing, which is more pronounced than ever before. Although, the major rivers are still flowing, unfortunately, the canals, which once surrounded the study area are disappearing. Recently, the government of Bangladesh has taken initiatives to recover small and large inland waterbodies and rivers. Some practical actions against the encroachment to the river, remarking the floodplain area, and restoration of the natural flow of the river course have been observed. The positive impact of these initiatives can also be discerned in the land classification between 2010 and 2020, as there was an increase in the river area. Though the rivers of Dhaka benefited due to the initiative, from our analysis Gazipur which also shares the common rivers did not get benefits, rather the river area decreased.

Translating findings into effective policies

The conversion of land use is a natural phenomenon; however, manmade decisions significantly influence the process. Analyzing the land use change pattern for the last 30 years, it is evident that land use change happened due to anthropogenic activities rather than natural reasons. Dhaka and Gazipur have experienced massive land use changes due to poor policy framework, lack of policy implementation, insufficient political interest, and economic benefits. Dhaka (formerly known as Dacca) city master Plan 1959, which was the first attempt to guide the development activities, has neither been implemented properly nor updated. One of the primary reasons for the failure was the inadequacy of population projections. It became evident that the city's rapid expansion exceeded the planned territory, ultimately resulting in the complete failure of policy implementation (Hossain and Ahmed 2018). Dhaka was expanding outside the scope of the Master Plan and therefore, a new strategy for land use management "Dhaka Metropolitan Development Plan (DMDP) 1995–2015" was created. Nevertheless, the DMDP 1995–2015 had hardly been implemented in terms of the environmental conservation viewpoint. After being unsuccessful at the second attempt, the Dhaka Structural Plan (DSP) 2016–2035 (draft) was developed, which undertook a more integrated approach to address those issues. The DSP identified 20 key "*Special Development Policies*" considered by DMDP 1995–2015, and commented that at least 11 were either "not achieved or no action was taken", whereas only three of them were "successfully implemented" (RAJUK 2015).

The DSP 2016–2035 also suggested various strategic regions for improved land-use management by categorizing lands into agricultural, central urban, outer urban, and growth management zones, among others. The plan designated forest areas, rivers, and canals, as "conservation areas". It is noteworthy to mention that the agricultural area has also been classified within the same category as the conservation area, referred to as an "urban control area." This categorization reflects a comprehensive approach that was lacking in prior policies. Executing the plan has always been a challenge, particularly when there is a lack of integration among stakeholders, including landowners, government departments, and ministries. This can be an even bigger challenge than policy preparation. However, the DSP did not mention or bring the ESs or the valuation of the ecosystem services approach in land management.

Simultaneously, the carrying capacity of the population and industries needs to be studied in the study area. If the number of industries exceeds the carrying capacity, decentralization could be an important management step. We found that the DSP 2015–2035 (draft) covers a lot of the issues/challenges that have been mentioned beforehand, however, after almost 8 years of the draft policy, very little has been achieved or implemented. Therefore, now there is a shift from "not included in the policy" to "not implemented in the ground". According to the findings of the present study, the land-use plan may be designed to emphasize conserving tree vegetation, rivers, and waterbodies, and promote sustainable agriculture, consecutively, all of which have depicted the most value in ecosystem service in the area. The promotion of "need-based" rather than "greed-based" conversion of landuse would promote higher integrity of the natural environment and ensure higher ecosystem services.

In light of the distinct characteristics exhibited by these two districts concerning land use change, we recommend the formulation of two distinct sets of land management policies, each tailored to the specific attributes of its respective district. Ideally, these policies should operate at a local scale, with a preference for granularity down to the upazila level. Furthermore, the policies should be oriented toward addressing the unique challenges and issues prevalent within each district. In Gazipur district, particularly within areas such as Sreepur, Kapashia, and Gazipur Sadar, as well as in Dhaka district, encompassing Dhaka city, Dhamrai, and Savar, substantial deterioration of tree vegetation has been observed (SI Figure A1, A2). Consequently, the local-scale land use policy must place a heightened emphasis on addressing this specific issue.

According to the study, Dhaka and Gazipur districts were experiencing significant loss of valuable tree vegetation cover. To address this issue coherently, urban planning strategies should prioritize the creation of green spaces, parks, and urban forests to offset this loss. Implementing green infrastructure projects, such as green roofs, permeable pavements, and urban wetlands, can further enhance urban biodiversity and provide vital ecosystem services within city limits. The study by Khan et al. 2023 also opined that developing numerous small-scale green spaces is more appropriate than developing larger but few green spaces.

To effectively manage the challenge of protecting and restoring waterbodies, it's crucial to enact zoning regulations that limit development in critical wetland areas. Additionally, river basin management plans should be established to protect river ecosystems and ensure sustainable water resource use. Given rapid population growth and increasing urbanization, there's an urgent need for comprehensive urban expansion management through zoning regulations, land-use planning, and infrastructure development to accommodate the growing population sustainably.

Urban settlement in Bangladesh is rising, leading to a decline in ecosystem service value due to poor decision-making (Abdullah et al. 2022). To address this, regular ecosystem service assessments are essential to understand their economic and ecological significance. These findings should then be used to inform decision-making processes and prioritize land-use practices that safeguard and enhance ecosystem services. Establishing a robust monitoring and assessment system to track changes in land use and the effectiveness of strategies is crucial. Additionally, incentives like tax breaks for green building initiatives or subsidies for eco-friendly agriculture should be considered.

Bangladesh Delta Plan (BDP 2100) goal no. 4 is focused on the "Conservation and preservation of wetlands and ecosystems and promotion of their sustainable utilization." Our study aimed at and identified land use-wise loss of ES experienced by two districts in Bangladesh. Assigning monetary values to these services serves the purpose of enabling policymakers and stakeholders to comprehend the tangible benefits that these ecosystems provide to society. By comparing the economic benefits derived from ecosystem services to the costs associated with their conservation and restoration, a strong economic argument can be made for investing in the preservation and restoration of wetlands and ecosystems when the benefits surpass the costs. This, in turn, underscores the importance of developing incentive mechanisms such as Payments for Ecosystem Services (PES) or market-based instruments like cap-and-trade systems. PES programs according to their monetary value can effectively compensate landowners or communities for their efforts in conserving and restoring tree vegetation, wetlands, rivers, and other ecosystems, thereby encouraging their sustainable and wise utilization.

In line with SDG 15 (protection of terrestrial ecosystems), this study investigates how land use changes, especially the conversion of tree vegetation, river, and urban areas, affect ecosystem services. The data generated can support the conservation and restoration of natural habitats. The transformation of forested areas into urban landscapes poses a significant challenge to achieving both SDG 11 (sustainable cities and communities) and SDG 15 (terrestrial ecosystem conservation).

The study emphasizes how crucial it is to develop cities sustainably and to prevent ecological services from being lost as cities grow. In relation to SDG 6 (water availability and sustainability), it also draws attention to the diminishing expanses of rivers and waterbodies. This research's findings highlight the importance of safeguarding water resources and the services they provide. In keeping with SDG 17 (collaboration for sustainable development), it encourages cooperation between academics, decision-makers, and communities, enabling a comprehensive approach to land.

Limitations and prospects for future research

The study was performed using 30-m resolution Landsat image considering the size of the study area. However, the use of higher-resolution images, for example, a 10-m Sentinel image could result in different estimations of the land use classification. The accuracy of the landuse classification suggests that mapping is quite accurate and any changes in the map would be minor. Moreover, to resolve the confusion between the river and waterbody (as they have a very similar spectral signature), a separate layer of the river was used for masking during the classification, which also increased the accuracy level of our classification.

No local value coefficients were found for specific types of LULC, so the study adopted the global value coefficients introduced by Costanza's et. (2014), that present values. The global scale values might not give perfect results while used on the local scale. However, in the absence of a benchmark study, determining the value of the dominant ecosystems on a local scale appears to be the best available approximation (Akber et al. 2018). Moreover, exact precision was less critical for policy formulation because our main goal was to examine changes in ecosystem service values over time. In contrast, the monetary value of ESs was influenced by market pricing, currency exchange rates, and inflation rates, making measurements difficult (Ainscough et al. 2018). One reliable manifestation of the ESV was that the CS which was lower than 1 in all cases, demonstrating that the results were relatively inelastic, which was also much similar to other studies (Tolessa et al. 2017; Rahman and Szabó 2021; Wang et al. 2021).

In terms of rivers, the pollution and quality of the river water have appeared as a bigger challenge than the conversion or loss of the river area. Industries and factories discharge wastewater into canals or connecting channels which ultimately gets discharged into the river (Hafizur et al. 2017; Kabir et al. 2022; Islam et al. 2011). The water quality of those rivers is so poor due to high pollution and the presence of heavy metals that even after treatment, it is unsuitable as drinking water (Islam et al. 2015). Islam et al. (2015) mentioned that industrial effluents and untreated sewerage have made the Buriganga river unsuitable for recreational activities such as swimming, fishing, or boating due to the high levels of pollutants, and bad odor. Therefore, it is very unlikely to use the maximum ESs from the rivers and other water bodies. However, when calculating the ESV, certain services, such as fish production and recreation values, have not been excluded. The extent of the geographical area where these services are still available and where they are not remains unidentified. Image classification cannot provide such information, and collecting data from the ground is an extensive task and out of the scope of the study.

Ecosystems may exhibit delayed responses to LULC changes, and these responses can be characterized as nonlinear, complex and dynamic (Wang et al. 2021). The presence of diverse preferences among various stakeholders concerning ecosystem services can introduce uncertainty when assessing the value of these services. Furthermore, the influence of climate change on LULC patterns and ecosystem services adds an additional layer of uncertainty to the equation. Additionally, it is worth noting that ecosystem services are frequently interconnected and susceptible to the influence of adjacent land uses, making it challenging to isolate their individual impacts. These factors represent potential sources of uncertainty within the ecosystem service valuation approach.

Despite these constraints, future research endeavors could consider the above mentioned limitation and tackle those issues. Nonetheless, it is crucial to recognize that this study provides valuable foundational data that can serve as a cornerstone for the development of policies aimed at preserving Bangladesh's invaluable natural resources.

Conclusions

In summary, this study highlights the complex interactions between land use change, ecosystem services and urban development in Bangladesh, especially in Dhaka and Gazipur districts. The findings underscore several significant points of consideration. First and foremost, the influence of various factors such as infrastructure development, electricity supply and accessibility to administrative and economic facilities has significantly shaped the development pattern of this region. Together these factors lead to a capital-centric approach to development, leading to widespread land conversion.

A notable observation is the significant loss of ecosystem services value (ESV), totaling $587.51 million, due to land use changes from 1990 to 2020. Particularly, the transition of trees and vegetation to other soil types explains much of this loss of ESV. Surprisingly, the economic benefits from land cultivation and infrastructure development seem to offset these losses, suggesting a complex economic and ecological relationship.

These findings have far-reaching implications. They emphasized the urgent need for sustainable land use practices, with a key focus on conserving forest areas and preventing deforestation. Strategic tree planting near river banks may prevent encroachment, although the selection and management of tree species needs further research. Additionally, there is a need to protect rivers and water bodies from illegal encroachment to conserve ESV and maintain the sustainability of water resources. What sets this study apart is its comprehensive geographical coverage, encompassing key economic districts characterized by industrialization and migration. Beyond Dhaka and Gazipur, these findings are important in informing high-level urban planning and policy-making efforts.

The study calls for a reassessment of Bangladesh's environmental policy, calling for the introduction of land use management and ESV assessments to complement existing pollution-focused measures. Furthermore, it highlights the need to establish local ESV coefficients as more and more publications adopt this approach.

Aligned with Sustainable Development Goals (SDG) 15, 11, and 6, this research provides the data needed to protect terrestrial ecosystems, promote sustainable urban planning, and ensure good governance. The knowledge gained here will inform environmental protection strategies, guide ecological restoration efforts, and facilitate precise zoning for effective land use policy planning.

To improve accuracy and reduce uncertainty in future research efforts, comprehensive analyzes integrating the value of ecosystem functions and annual land use data will be important. important to assess how ESV responds to ecosystem restoration projects. Such efforts will enhance our understanding of ecosystem services and land use dynamics, thereby contributing to the global discourse on sustainable development and environmental conservation.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40068-023-00316-5.

Supplementary Material 1

Authors' contributions

Raihan Sorker, Alamgir Kabir and Mohammad Wahidur Khan contributed to the study conception and research design. Raihan Sorker and Nowshin Nawar collected, and analyzed the data. Mohammad Wahidur Khan prepared the manuscript. Alamgir Kabir reviewed and supervised the total work.

Funding

Open Access funding enabled and organized by Projekt DEAL. The study did not receive any external funding.
Open Access funding enabled and organized by Projekt DEAL.

Data Availability

All data used in the study are publicly available on the Internet. Besides, the datasets and figures generated during this study are available from the corresponding author based on reasonable request.

Declarations

Ethical responsibilities of author

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Competing interests

The authors declare no competing interests.

Received: 23 August 2023 / Accepted: 23 September 2023

References

Abdullah HM, Islam I, Miah MG, Ahmed Z (2019) Quantifying the spatiotemporal patterns of forest degradation in a fragmented, rapidly urbanizing landscape: a case study of Gazipur, Bangladesh. Remote Sens Applications: Soc Environ 13:457–465. https://doi.org/10.1016/j.rsase.2019.01.002

Abdullah S, Adnan MSG, Barua D, Murshed MM, Kabir Z, Chowdhury MBH, Hassan QK, Dewan A (2022) Urban green and blue space changes: a spatiotemporal evaluation of impacts on ecosystem service value in Bangladesh. Ecol Inf 70:101730. https://doi.org/10.1016/j.ecoinf.2022.101730

Ahmed SS, Ahmed M (2017) Urbanization and Economic Development of Bangladesh: the primacy of Dhaka and Competitiveness. Bangladesh Economics Association

Ainscough J, Wilson M, Kenter JO (2018) Ecosystem services as a post-normal field of science. Ecosyst Serv 31:93–101. https://doi.org/10.1016/j.ecoser.2018.03.021

Akber MA, Khan MWR, Islam MA, Rahman MM, Rahman MR (2018) Impact of land use change on ecosystem services of southwest coastal Bangladesh. J Land Use Sci 13(3):238–250. https://doi.org/10.1080/1747423X.2018.1529832

Anderson JR, Hardy Ernest E, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data. USGS Prof Paper 964:1–40. https://doi.org/10.3133/pp964

Arifeen HM, Phoungthong K, Mostafaeipour A, Yuangyai N, Yuangyai C, Techato K, Jutidamrongphan W (2021) Determine the land-use land-cover changes, urban expansion and their driving factors for sustainable development in Gazipur Bangladesh. Atmosphere 12(10):1353. https://doi.org/10.3390/atmos12101353

Arowolo AO, Deng X, Olatunji OA, Obayelu AE (2018) Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. Sci Total Environ 636:597–609. https://doi.org/10.1016/j.scitotenv.2018.04.277

Byomkesh T, Nakagoshi N, Dewan AM (2012) Urbanization and green space dynamics in greater Dhaka. Bangladesh Landsc Ecol Eng 8(1):45–58. https://doi.org/10.1007/s11355-010-0147-7

Chen J, Sun B-M, Chen D, Wu X, Guo L-Z, Wang G (2014) Land use changes and their effects on the value of ecosystem services in the small Sanjiang Plain in China. Sci World J 2014:e752846. https://doi.org/10.1155/2014/752846

Chuai X, Huang X, Wu C, Li J, Lu Q, Qi X et al (2016) Land use and ecosystems services value changes and ecological land management in coastal Jiangsu, China. Habitat Int 57:164–174. https://doi.org/10.1016/j.habitatint.2016.07.004

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, Sutton P, van den Belt M (1997) The value of

the world's ecosystem services and natural capital. Nature, 387(6630), Article 6630. https://doi.org/10.1038/387253a0Costanza
Costanza R, De Groot R, Sutton R, Van Der Ploeg P, Anderson S, Kubiszewski SJ, Farber I, S, Turner RK (2014). Changes in the global value of ecosystem services. Global Environmental Change, 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002
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, Kumar P, McVittie A, Portela R, Rodriguez LC, ten Brink P, van Beukering P (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
Dewan A, Yamaguchi Y (2008) Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during 1960–2005. Environ Monit Assess 150(1–4):237–249. https://doi.org/10.1007/s10661-008-0226-5
Dewan AM, Yamaguchi Y (2009) Land use and land cover change in Greater Dhaka, Bangladesh: using remote sensing to promote sustainable urbanization. Appl Geogr 29(3):390–401. https://doi.org/10.1016/j.apgeog.2008.12.005
Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC, Wilkinson C, Alberti M, Folke C, Frantzeskaki N, Haase D, Katti M, Nagendra H, Niemelä J, Pickett STA, …, Tidball K (2013) Stewardship of the biosphere in the urban era. In: Elmqvist T, Fragkias M, Goodness J, Güneralp B, Marcotullio PJ, McDonald RI, Parnell S, Schewenius M, Sendstad M, Seto KC, Wilkinson C (eds) *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*: A Global Assessment. Springer Netherlands, pp 719–746. https://doi.org/10.1007/978-94-007-7088-1_33
Fang S, Gertner G, Wang G, Anderson A (2006) The impact of misclassification in land use maps in the prediction of landscape dynamics. Landscape Ecol 21:233–242. https://doi.org/10.1007/s10980-005-1051-7
Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making. Ecol Econ 68(3):643–653. https://doi.org/10.1016/j.ecolecon.2008.09.014
Gashaw T, Tulu T, Argaw M, Worqlul A, Tolessa T, Kindu M (2018) Estimating the impacts of land use/land cover changes on ecosystem service values: the case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia. Ecosyst Serv 31:219–228. https://doi.org/10.1016/j.ecoser.2018.05.001
Hafizur RM, Nuralam HM, Rumainul IM (2017) Investigation of physicochemical parameter, heavy metal in Turag river water and adjacent industrial effluent in Bangladesh. J Sci Technol Environ Inf 5(1):347–360
Hasan MN, Hossain MS, Islam MR, Bari MA, Karim D, Rahman MZ (2013) Trends in the availability of agricultural land in Bangladesh. Soil Resource Development Institute (SERDI), Ministry of Agriculture, Bangladesh, Dhaka. Retrieved May 17, 2022, from http://www.nfpcsp.org/agridrupal/sites/default/files/Trends-in-the-availability-of-agricultural-land-in-Bangladesh-SRDI-Supported-by-NFPCSP-FAO.pdf
Hossain MA, Ahmed M (2018) Managing urban growth and development in dhaka city, Bangladesh. Sustainable development goals and urbanization in developing countries. Springer, Cham, pp 111–130
Hossain Bhuiyan MA, Chandra Karmaker S, Bodrud-Doza M, Rakib MA, Saha BB (2021) Enrichment, sources and ecological risk mapping of heavy metals in agricultural soils of dhaka district employing SOM, PMF and GIS methods. Chemosphere 263:128339. https://doi.org/10.1016/j.chemosphere.2020.128339
Hu H, Liu W, Cao M (2008) Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China. Environ Monit Assess 146(1–3):147–156. https://doi.org/10.1007/s10661-007-0067-7
Islam KK, Hyakumura K (2019) Forestland concession, land rights, and livelihood changes of ethnic minorities: the case of the Madhupur Sal forest. Bangladesh Forests 10(3):288
Islam MM, Mahmud K, Faruk O, Billah MS (2011) Textile dyeing industries in Bangladesh for sustainable development. Int J Environ Sci Dev 2(6):428
Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Islam MK (2015) Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. Ecol Ind 48:282–291
IUCN (2016) The state of the rivers of South Asia: Bangladesh Country Report. New Delhi, India: International Union for Conservation of Nature. Retrieved from https://portals.iucn.org/library/node/46654
Jiang W, Wu T, Fu B (2021) The value of ecosystem services in China: a systematic review for twenty years. Ecosyst Serv 52:101365. https://doi.org/10.1016/j.ecoser.2021.101365
Kabir A, Sraboni HJ, Hasan MM, Sorker R (2022) Eco-environmental assessment of the Turag river in the megacity of Bangladesh. Environ Challenges 6:100423. https://doi.org/10.1016/j.envc.2021.100423
Khan MW, Hossain MS, Alam M (2023) GIS-based analysis to identify the distribution and accessibility of urban green space in Dhaka Metropolitan city, Bangladesh. J Geographic Inform Syst 15(01):35–52. https://doi.org/10.4236/jgis.2023.151003
Kindu M, Schneider T, Teketay D, Knoke T (2016) Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the ethiopian highlands. Sci Total Environ 547:137–147. https://doi.org/10.1016/j.scitotenv.2015.12.127
Kreuter UP, Harris HG, Matlock MD, Lacey RE (2001) Change in ecosystem service values in the san Antonio area. Tex Ecol Econ 39(3):333–346. https://doi.org/10.1016/S0921-8009(01)00250-6
Lal P (2003) Economic valuation of mangroves and decision-making in the Pacific. Ocean & Coastal Management 46(9):823–844. https://doi.org/10.1016/S0964-5691(03)00062-0
Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. Biometrics 33(1):159–174. https://doi.org/10.2307/2529310
Li RQ, Dong M, Cui JY, Zhang LL, Cui QG, He WM (2007) Quantification of the impact of land-use changeson ecosystem services: a case study in pingbian county, China. Environ Monit Assess 128(1–3):503–510. https://doi.org/10.1007/s10661-006-9344-0
Millennium Ecosystem Assessment (2005) *Ecosystems and human well-being: Biodiversity Synthesis*. World Resources Institute. Island Press, Washington Millennium Ecosystem Assessment, Retrieved DC (2005) January 12, 2022, from http://www.millenniumassessment.org/documents/document.354.aspx.pdf
Moniruzzaman M, Thakur PK, Kumar P, Ashraful Alam M, Garg V, Rousta I, Olafsson H (2021) Decadal urban land use/land cover changes and its impact on surface runoff potential for the Dhaka city and surroundings using remote sensing. Remote Sens 13(1). https://doi.org/10.3390/rs13010083
Nawar N, Sorker R, Chowdhury FJ, Mostafizur Rahman M (2022) Present status and historical changes of urban green space in Dhaka city, Bangladesh: a remote sensing driven approach. Environ Challenges 6:100425. https://doi.org/10.1016/j.envc.2021.100425
Plummer ML (2009) Assessing benefit transfer for the valuation of ecosystem services. Front Ecol Environ 7(1):38–45. https://doi.org/10.1890/080091
Rahman MM, Szabó G (2021) Impact of land use and land cover changes on urban ecosystem service value in Dhaka. Bangladesh Land 10(8):793. https://doi.org/10.3390/land10080793
Rahman K, Zhang D (2018) Analyzing the level of accessibility of public urban green spaces to different socially vulnerable groups of people. Sustainability 10(11):3917. https://doi.org/10.3390/su10113917
Rahman MM, Rahman MM, Guogang Z, Islam KS (2010) A review of the present threats to tropical moist deciduous Sal (Shorea robusta) forest ecosystem of central Bangladesh. Trop Conserv Sci 3(1):90–102
Rahman MU, Dey T, Biswas J (2022) Land-use change and forest cover depletion in Bhawal National Park, Gazipur, Bangladesh from 2005 to 2020. Environ Monit Assess 195(1):201. https://doi.org/10.1007/s10661-022-10764-8
Rai R, Zhang Y, Paudel B, Li S, Khanal NR (2017) A synthesis of studies on land use and land cover dynamics during 1930–2015 in Bangladesh. Sustainability 9(10):1866. https://doi.org/10.3390/su9101866
RAJUK (2015) Dhaka Structure Plan, 2016–2035 (Draft-Consultation Copy), Dhaka. Retrieved on September 18, 2022, from https://rajuk.portal.gov.bd/sites/default/files/files/rajuk.portal.gov.bd/page/0a05e9d0_03f7_48e4_bfd5_cad5fbcd5e23/2021-06-22-08-35-c8b98a96d0cadc8d87fa1c61f56966bb.pdf
Richards JA (2013) Supervised classification techniques. In J. A. Richards (Ed.), *Remote Sensing Digital Image Analysis: An Introduction* (pp. 247_318). Springer. https://doi.org/10.1007/978-3-642-30062-2_8
Sayed A, Amir M, Bhuiyan M, Ashraful M, Chowdhury MA, Kabir MM (2015) Effects of industrial agglomeration on land-use patterns and surface water quality in Konabari, BSCIC area at Gazipur. Bangladesh 4:2319–1414
Sultana MS (2012) Toxic metal contamination on the river near industrial area of Dhaka. Univers J Environ Res Technol. https://www.environmentaljournal.org/2-2/ujert-2-2-6.pdf
Temesgen H, Wu W, Shi X, Yirsaw E (2018) Variation in ecosystem service values in an agroforestry dominated landscape in Ethiopia: implications for land use and conservation policy. Sustainability 10(1126):1–20
The Daily Star (2022), September 14 There's still time to save Gazipur [Opinion]. Retrieved September 18, 2022, from https://www.thedailystar.net/views/opinion/news/theres-still-time-save-gazipur-2185336

Tianhong L, Wenkai L, Zhenghan Q (2010) Variations in ecosystem service value in response to land use changes in Shenzhen. Ecol Econ 69(7):1427–1435. https://doi.org/10.1016/j.ecolecon.2008.05.018
Tolessa T, Senbeta F, Kidane M (2017) The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. Ecosyst Serv 23:47–54. https://doi.org/10.1016/j.ecoser.2016.11.010
Uddin K, Gurung DR (2008) Land cover change in Bangladesh- a knowledge based classification approach. In Proceedings of the 10th International Symposium on Hill Mountain Remote Sensing Cartography (pp. 45–52)
Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277(5325):494–499. https://doi.org/10.1126/science.277.5325.494
Wang Y, Zhang X, Peng P (2021) Spatio-temporal changes of land-use/land cover change and the effects on ecosystem service values in Derong County, China, from 1992–2018. Sustainability 13(2):827. https://doi.org/10.3390/su13020827
World Bank (2012) Bangladesh-towards accelerated, inclusive and sustainable growth: Opportunities and Challenges: Overview (Vol. II, Main Report). Washington, DC, USA: World Bank. Retrieved January 22, 2022, from http://documents.worldbank.org/curated/en/132321468014348379/Overview
Xue M, Ma S (2018) Optimized land-use Scheme based on Ecosystem Service Value: Case Study of Taiyuan, China. J Urban Plan Dev 144(2):04018016. https://doi.org/10.1061/(asce)up.1943-5444.0000447
Yi H, Güneralp B, Filippi AM, Kreuter UP, Güneralp İ (2017) Impacts of land change on ecosystem services in the San Antonio River Basin, Texas, from 1984 to 2010. Ecol Econ 135:125–135. https://doi.org/10.1016/j.ecolecon.2016.11.019
Zhao B, Kreuter U, Li B, Ma Z, Chen J, Nakagoshi N (2004) An ecosystem service value assessment of land-use change on Chongming Island, China. Land Use Policy 21(2):139–148. https://doi.org/10.1016/j.landusepol.2003.10.003
Zinia NJ, McShane P (2021) Urban ecosystems and ecosystem services in megacity Dhaka: Mapping and inventory analysis. Urban Ecosyst 24(5):915–928. https://doi.org/10.1007/s11252-020-01076-1

Publisher's Note